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Proton Bombardment in Aurora

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Summary

The paper describes developments in observations of recently discovered new type of aurora the proton aurora i.e. "hydrogen field" which systematically appears in the auroral zone often at quiet magnetic conditions and moves to equator with rising magnetic disturbance. The hydrogen field is nearly homogeneous wide band with borders along magnetic parallels. There is no other certain evidence on concentration of hydrogen emission in any other distinct auroral form. The magnetic zenith emission profile is nearly constant possibly with only minor variations. Published data cannot serve to derive with certainty the height of hydrogen emission in hydrogen field and initial proton energy spectrum at low energies.

The discovery of proton aurora as distinct phenomenon completes the picture of particle bombardment in disturbed upper atmosphere and stresses the lack of understanding of auroral accelerating mechanisms.

1.

Observational results

1.1. Introduction

First auroral spectra with broadened hydrogen emission were obtained by Vegard in 1939 (1). Later observations of H_β (2,3) and H_α, H_β and H_γ (4,5) confirmed identification of registered emissions as hydrogen lines and proved that boradening is caused by doppler effect. Meinel (6,7) obtained doppler profiles separately from magnetic zenith and magnetic horizon and showed that emitting hydrogen atoms are moving approximately along magnetic lines of force and it was confirmed directly by Gartlein[8] by simultaneous spectrographing of fixed point of the same homogeneous arc in magnetic zenith and magnetic horizon from two stations.

1.2. Morphology of proton bombardment

Sistematic hydrogen emission studies at the auroral and subauroral zone (9 - 12) showed that usually before local midnight the region of proton bombardment shifts gradually from north to the south (in the Northern hemisphere) and after local midnight back from south to north, though sometimes much more complicated picture of repeated movements can be seen. Region of proton bombardment, "the hydrogen field" may be described as wide band of nearly homogeneous brightness. The borders of this band lay approximately along magnetic parallels (11) from horizon to horizon. Latitudinal spread is at least up to 15° while the lowest observed value is about 1° (11). To the north from hydrogen field (in the Northern hemisphere) the usual aurora ~~[illegible]~~

excitated by electrons in situated. Regions of proton and electron bombardment are usually separated by dark emissionless band (11,12,13). For higher magnetic activity both these regions move to south (10, 12, 13, 14). But in auroral zone hydrogen emission may appear during quiet magnetic field (9, 10, 15). These conclusions are in good agreement with earlier statistical results by Gartlein (16) and Montalbetti and Jones (15). With such picture the majority of earlier observations of auroral hydrogen such as by Vegard (2, 3), Fan and Schulte (17), Omholt (18, 19), Romick and Elvey (20) and others can be put into agreement.

Sometimes however hydrogen emission is registered simultaneously with usual electron aurora. The regular picture described above is disturbed especially during strong magnetic storms.

Hydrogen bombardment at zenith on low latitude stations is registered much rarely than electron bombardment. Apparently hydrogen field is surrounded from the south as from the north by regions of electron penetration (14). Many measurements have been made with the aim to find the enhancement of hydrogen emission in any usual bright sharp defind auroral form, but all with negative result (11).

In the auroral zone the hydrogen emission may be observed nearly every night with the intensity of the H_α line at least 100 R (9,11).

1.3. Height luminosity distribution

Measurements of brightness distribution of hydrogen emission in the function of zenith distance were made by different methods (7, 9, 11, 19). But if the geographical extent of hydrogen field at the moment of observations is unknown, the brightness distribution measured from one station can not allow to construct the height luminosity distribution. For this

must be used precise simultaneous observations from a number of stations or rocket measurements in L_α line similar to airglow height determinations are needed.

According to Rees (21) detailed photometrical triangulation of typical hydrogen field gave for height of lower edge 108 km and sharp intensity decrease with height above maximum. But observational method and details are not mentioned.

1.4 Hydrogen line profiles

Extensive observational material have shown that in overwhelming majority of cases auroral hydrogen profiles are practically identical within observational errors.(3, 5, 6, 8, 9, 11, 19, 22, 23, 24, 25) Only some cases of "narrow" profiles in magnetic zenith have been stated (8, 22, 23). Small variations in H_α and H_β zenith profiles such as different displacement of intensity maximum, the rate of the intensity decrease in the violet tail at least partly are due to contamination of hydrogen radiation scattered from high magnetic zenith angles and often (especially with low resolution) hardly can be discriminated from blending bands. Meanwhile some variations may be significant. More detailed fast observations with high resolution are needed.

In any case, not a single magnetic zenith profile is published or stated with the intensity maximum in the energy range $\geq$10 kev

1.5 Balmer decrement

Some information may be gathered from Balmer decrement of auroral hydrogen (relative intensities of Balmer lines) but the measurements are very difficult and there are still only few data. These are described in the following table.

Author	$I(H_\alpha)$	$I(H_\beta)$	$I(H_\gamma)$
Vegard (5)	7	1	-
Galperin (9)	-	1	0.8
Shuyskaya (26)	2.8 1.0 [illegible]	1 1 1	0.9 [illegible] [illegible]
Deehr (27)	$1.65^{+0.58}_{-0.34}$	1	-

Successive intensities given by Deehr (27) apparently lead to conclusion that $I(H_\alpha)/I(H_\beta) \sim 2$ in periods of low intensity of (0,2) $1NGN_2^+$ band, but that $I(H_\alpha)/I(H_\beta) \sim 1$ during auroral break-ups. All these measurements apparently were not corrected for contamination of hydrogen radiation scattered from directions out of line of sight. So any conclusions about possible variations of Balmer decrement must be postponed.

Higher Balmer numbers than H_γ and Paschen lines have not been detected for the present with certainty.

1.6 Intensity correlations

Many authors finded correlation between hydrogen lines' intensity and high-altitude forbidden atomic emissions 6300-6364 [OI] and 5200 [NI] (5, 9, 13, 18, 20, 27, 28), but Evlashin (10) obtained contrary result. Ivanchuck (28) showed that mean intensity ratio of $I(H_\beta)/I[(0-3)1NG]$ rises together with ratio $I(5200)/I[(0-3)1NG]$. It was found (9) that in the spectra with hydrogen emission not only forbidden but often permitted atomic lines are also relatively enhanced which makes such spectra similar to ones of high altitude type A red aurora, and this was confirmed in (28).

Vaisberg (29) by extensive studies with auroral spectrometer showed that in hydrogen field the intensities of all strong emissions from ultra-violet to infrared regions are nearly proportional to H_β intensity. But in comparing these with spectra of electron aurora some peculiarities may be found for example, in hydrogen fields the relative intensity of Meinel bands of N_2^+ is lower and the intensity of 5004 NII is higher. The ratio $I(H_\beta)/I[(0,2)1NG] \sim 1$ in hydrogen fields and may be up to 1,5.

Some cases are reported when the ratio $I(H_\beta)/I[(0,2)1NG] \gg 1$ (20, 23, 30) and simultaneously H_β zenith profile become "narrow" (23).

1.6. Direct measurements of auroral protons

In the IGY early in the 1958 two series of rocket auroral measurements were performed. In one series (31) in four cases energetic ionic (most probably proton) beams were detected. Their integral energy spectra for energies more than about 160 kev. can be described by power law with $\gamma \sim -1,2$. For energies less than about 160 kev. the spectrum is more flat. The ionic flux is isotropic in the pitch-angle range from 0° to 75°. The most intense flux (with steep energy spectrum) was detected in situation similar in description to hydrogen field. In the other series (32) in the case also according to description similar to hydrogen field the flux of the form $J(>E) \approx 2,5 \left(\frac{E_{kev}}{1000}\right)^{-1,5} cm^{-2}\ sec^{-1}\ ster^{-1}$ was detected. Simultaneous ground observations of H_β with auroral spectrometer showed $Q(H_\beta) = 6 \cdot 10^7$ photon/sm^2sec. and intensity of integral auroral light registered by photomultiplier with S-11 spectral sensitivity curve as 0,05 erg /cm^2sec.

2. Theory of auroral hydrogen emission

2.1. Emission rate per incident proton

When a proton beam passes through a gas (or gas mixture) a number of charge-changing elementary processes take place which lead to creation of neutral atoms and negative ions. Fractions of the total moving beam with charges "+" , "o" and "-" can be found from equations given in (32). Some processes lead to appearance of the excited atoms. The H^- fraction of incident proton in the molecular azot, oxygen and hydrogen beam do not exceed 2% and usually its role is not taken into consideration though respective cross-sections are not known.

The most important characteristic of proton beam emissivity is the dependence Fnn' (v) of photon emission rate per incident proton per unit diminution of velocity (or per atm-cm path length). Unfortunately for the present there is no experimental data on Fnn' determination directly from photon beam in upper atmospheric constituents in the whole region from 0,2 to at least 30 kev. The excitation of hydrogen emissions was theoretically calculated by the equations of statistical equilibrium and ionization equilibrium (look 34) with the use of the effective cross-sections calculated by Bates and his associates (35,36) for proton beam in atomic hydrogen and also with experimentally obtained data for protons in azot, oxygen and air. The resulting curve for Fnn' (v) has broad maximum for H_α at the velocity of about 2000 km/sec (E~20 kev) and sharp decrease with the diminution of velocity to ~1000 km/sec (~5kev).

The form of the Fnn' (v) dependence may be evaluated in another way also. Suppose that proton is incident on atmosphere of pure N_2.

Experimental data on number of capture and loss cycles in a hydrogen beam in function of energy $\frac{dN_c}{dE}$ in azote are given in (33). The ratio of captures on the 3[rd] quantum level to all captures for energies of 1 - 4 kev has been measured (37), and is close to theoretical values for $H + H^+$ (35) for such energies. So for E >5 kev this ratio may be taken from (35). Such calculation gives the Fnn' (v) curve only from capture from N_2 on the 3[d] level (it seems that atmospheric gas mixture will not change this result significantly) with a broad maximum at E= 30kev and the total number C (where $C = \int_0^{v_0} F_{n\alpha}(v)\, dv$) equal to 76$H_\alpha$ quanta per incident proton of energy E > 300 kev. Analogous estimates of the position of the maximum of Fnn' curve can be made by the use of adiabatic criterion of Massey, though validity of such estimates for excitation processes apparently have not been proved.

In short, all the data which use the excitation probabilities by capture to excited state from (34) lead to sharp decrease of excitation efficiency at low energies (E<10 kev). But the absence of direct experimental measurements especially with atomic oxygen make this most important point somewhat uncertain.

2.2. The role of protons in auroral excitation

As has been calculated (for example see Chamberlain (34)) for pure proton beam with the above mentioned Fnn' function the quantum intensity ratio Q (H_β)/Q (3914)[x] > 0,3 for initial proton energies E< 100 kev and this ratio rises with the diminution of

x) Q (3914) is the quantum intensity of (0,0) band 1NGN_2^+ per cm^2 per sec, Q (4709) is the same for (0,2) band.

initial proton energy. Taking Q (3914)/Q(4709)=17,5 (34) we have Q (H_β)/Q(4709) > 5.... As described above even in usual hydrogen field this ratio is about unity (29) and only in some cases (20, 23, 30) values much more than unity were registered. This means that even in usual hydrogen field the main (at least comparable) part of luminocity of atmospheric gases apparently is excited by electrons and pure proton bombardment is a very rare case, possibly connected with protons of especially low velocities (23).

2.3. Proton flux anisotropy

Another important characteristic of proton influx is the pitch-angle distribution function $N(\theta)$ ($cm^{-2}sec^{-1}ster^{-1}$). Using $N(\theta)$ (supposing it is independent of velocity) and Fnn' (v) the formulae for the line profiles in magnetic zenith, magnetic horizon and intermediate directions may be derived (34, 38, 39). It is evident from symmetry considerations that for isotropic proton flux for $\theta < 90^\circ$ per unit solid angle on a unit square perpendicular to magnetic force line $N(\theta)$ = const (or $\eta(\theta)\cos\theta$ = const, where $\eta(\theta)$ is the particle intensity) the form of magnetic zenith and magnetic horizon profiles coincide (in the intermediate directions a slight asymmetry will conserve). Therefore the fact that typical observed profiles in these two directions are markedly different means that irrespective of initial proton energy spectrum the beam is anisotropic significantly. Quantitative estimates of the $N(\theta)$ function approximated by the form $N(\theta) = K \cos^{n+1}\theta$ show that observed profiles lead to $-1 \leq n \leq 3$. This may be compared with nearly

isotropic particle intensity $\eta(\theta)$ measured from rocket (31), that is $n \approx 0$, for $E \geq 160$ kev.

2.4. Proton energy spectrum

As we have no experimental justification that proton flux anisotropy is independent of energy in the region $E < 100$ kev we cannot be sure that the full distribution function of proton beam $N(v_0/\theta)$ permit the separation of variables but such supposition is usually made. Both Fnn' (v) and $N(\theta)$ functions are needed for derivation of $\Psi(v_0)dv_0$ — the velocity dependent part of distribution function. Assuming the abovementioned form for Fnn' (v) and $N(\theta)$ and taking $\Psi(v_0)dv_0$ = const $v_0^{-s}dv_0$ to a sharp cutoff at some minimum velocity v_{min} Chamberlain (34) shown that for $v > v_{min}$ observational profiles lead to $2 \leq s \leq 3$ in the energy region of order 10 ÷ 1 kev. So compromise distribution function may be written as

$$N(v_0|\theta)\,dv_0\,d\theta = const \cdot \cos\theta \cdot v_0^{-2.5}\,dv_0\,d\theta$$

For energies $E > 100$ kev the energy spectrum is much more steep (31, 32) and variable. The energy range 5 ÷ 150 kev for the present apparently has not been studied by any method. However some estimates could be made from comparison of simultaneous rocket and ground observations (32) if the registered H_β profile was published. Supposing that the profile was of typical form, it can be evaluated that as much as $3 \cdot 10^5$ ions/cm^{2}sec ster with $E > 20$ kev might penetrate to auroral heights at the moment of the experiment without being noticed by profile observations. This is only about 3 times lower than extrapolation used in (32) gives. But for lower energies of order of 1 kev the flux must

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exceed significantly that extrapolated in (32).

3. Discussion

This last conclusion as other interpretation problems for example, angular distribution, the presence of electron bombardment in hydrogen field and so on depend on assumed form of Fnn' (v) function. It must be mentioned that sharp low energy cutoff in this function appear only because theoretical calculations for $H^{+}+H$ collisions (35) are applied to upper atmospheric conditions. If for atmospheric gas mixture the ratio of captures to an excited state to all captures by proton does not vary so sharply in the region $5 \div 15$ kev as the results of (35) imply the maximum of Fnn' curve (see 34) may shift significantly to lower energies. If our present knowledge (34) on the form and absolute values of Fnn' is completely wrong the scope of observational data for the present (21, 25, 31, 32) cannot exclude possibility that typical hydrogen field emission is caused by protons of energies of tens of kev.

In any case the maximum of proton differential energy spectrum must lay in the region $1 \div 30$ kev. The hydrogen emission problem now may be analysed from different sides. The height of maximum luminocity, the hydrogen emission cross sections in the region mentioned above and especially direct experiment on proton injection or proton registration in the upper atmosphere would be decisive. The systematic search for hydrogen emission profile variations and $Q(H_\beta)/Q(3914)$ ratio also may lead to important information on proton bombardment.

The following aspects of incident proton beam cannot escape attention. Firstly, the position of maximum proton differential energy spectrum is similar within an order of magnitude to one of auroral electron spectrum and it is hardly a fortuitous coincidence. Secondly, proton spectrum in comparison to auroral electron one typically has long high energy tail up to some hundreds of kev which possibly signifies to acceleration of protons in the upper atmosphere by some analogy to Fermi acceleration (for example by hydromagnetic waves) and not by electric field. It is clear that the wide energy spectrum and systematic geographical picture of proton bombardment is in harmony with the idea of their local acceleration in the upper atmosphere but not with their penetration to auroral heights directly from solar stream.

The discovery of sistematic picture of proton bombardment means that the sense of the notion "aurora" must be precised as low energy particle bombardment of upper atmosphere but not only distinct easily visible bright formations. Usual all-sky and other auroral morphology studies deal not with aurora in general but only with bright electron aurora while proton aurora with its low emission intensity is a distinct and remarkable upper atmospheric phenomenon completing the picture of upper atmospheric disturbance. It is especially important for general auroral theory.

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G.S. IVANOV-KHOLODNY

THE ROLE AND THE SOURCE OF PARTICLES IN IONOSPHERE AND AURORAE FORMATION

(Survey)

Corpuscules of various kinds were found in the upper atmosphere by means of rockets and satellites. Recently many papers on this question have been written. They are investigated by different methods and in various aspects. The present survey deals only with corpuscular fluxes, which consist of electrons and penetrate into a considerable atmosphere depth. These, corpuscular fluxes are likely to be of great importance in causing ionosphere events and aurorae. While studying such corpuscular flumes there arise principle questions, concerning their source and origin, electrons acceleration, and conditions of their penetration into the atmosphere what is connected with the ionisation (phenomenon, ~~atmospherics~~ and ~~illumination~~ emission of the atmosphere. Many of these important problems has not been solved yet, therefore it is of great importance to draw attention to them.

The first problem of the upper atmosphere physics occurred in the ~~history of Mankind~~ astronomy was the explanation of auroras. However the problem is still not solved though many questions connected with the upper atmosphere, which were raised ... long ago and some of them quite recently, has been solved. Auroras have their maximum ~~repetition~~ frequency and intensity in the region of

2.

20-25° just round the geomagnetic poles, but they differ greatly in form, their slight glow is sometimes observed at rather low latitudes /I,2/. It was observed long ago, that intensive aurorae occur approximately a day after solar flare and generally aurora activity correlates with solar activity Thus aurorae are the display of solar activity. On the other hand, aurorae occur simultaneously with geomagnetic storms and sometimes they cover vast regions of the Earth, what makes us consider them to be a global geophysical phenomenon. These features stipulated the search of a theory, which might have explained aurorae by means of charged corpuscules fluxes, coming to the Earth from the Sun. The first such theory was worked out by Birkeland and then developed by Störmer and Vegard. The theory seemed to give a good qualitative explanation to auroral zones location and their connection with geomagnetic disturbances. The trajecteries of charged particles movements in the magnetic field were studied in detail. However, this theory in its original form at close examination could not give a satisfactory quantitative explanalitom to such facts as particles spread in the interplanetary medium from the Sun to the Earth, particles ability to overcome the magnetic field and the earth atmosphere, peculiarities of particle effects on the geomagnetic field and nature of the latter variations, and excitation of typical aurorae glows, etc. Chapman, Ferraro and Martyn, Bennett and Hulburt, Alfven, Petukhov and other developed the theory. These theories will not be discussed here as their rather detailed criticism survey was recently given by Chamberlain /3/. Owing to great difficulties, arous while explaining aurorae and geomagnetic disturbances by dire effect of comparatively slow solar corpuscules, other theories were suggested, which consider charged particles acceleratic in the upper earth atmosphere above auroral zone.

Nowadays, it became clear from other different data, that aurorae are excited by electron fluxes with the energy of IO kev and less /4,5/, therefore the theory should explain the origin of such electron fluxes. Apparently, at present th aim of theories of aurorae is to find the acceleration mec mechanism and the source of soft electron fluxes, which exciti aurorae, their connection with solar events, geomagnetic storms, and other phenomena.

When earth artificial sattelites and rockets investigations resulted in finding the earth radiation belts, consistir of electron and proton fluxes, which are advanced in high geomagnetic latitudes, naturally, there was made an attempt to connect aurorae origin with these belts.

It is interesting, that a year before the earth radiati belts had beed revealed by Singer /6/ while developing a theor explaining magnetic storms and aurorae by shock wave coming from the Sun, suggested a trap mechanism of charged particles in Stormer prohibited according th Stormer region of the geomagnetic field. He indicated herewith that particles

with small pitch angles could reach deep atmosphere layers and cause aurorae, night air glow, and ionosphere ionisation.

After the radiation belts were revealed another sources of their trapped particles were suggested. The most popular was the hypotheses of the belts formation due to albedo neutrons decay, suggested by Singer /7/, Vernov et al. /8/, Kellogg/9/ and Hess /IO/. This hypothesis was developed in detail by a numb number of investigators in I959-I960 /II,I2, I3,I4/ and later by others.

These investigations resulted in obtaining intensity distribution in space, energy spectrum, and distribution of trapped particles velocities, calculation of their life time and discussion of the most probable ways of particles leakage loss from the radiation belts. It was as well indicated that albedo neutrons decay could be a source of only the inner more stable radiation belt. While considering the connection of the earth radiation belts with aurorae, let us pay attention to hypotheses explaining the outer radiation belt. Note however, that lately Pizzella /I5/ detected appreciable radiation intensity variations in the inner radiation belt following intense chromospheric flares. These variations are so great , and characteristic time of normal resteration intensity level is so short, that there appear serious grounds doubt that only neutron source contributes to the inner radiation belt.

A good stimulus, but simultaneously a touchstone for theories of the radiation belts origin and particles loss from the belts was the investigation of their connection with aurorae and the earth ionosphere.

Experimental data on the relation of the radiation belts to AURORAE

One of the reasons which made some of the scientists think of a certain connection between the radiation belts and aurorae (Van Allen /I6,I7/, Rode /I8/) was the detection of the close approach of the aurora latitudes to the outlet of magnetic lines of force from the outer radiation belt, V.I. Krassovsky et al. /I9, 20/ connected the occurance of the radiation belts in the high latitudes with the atmosphere heating and expansion above these regions. The electron fluxes measured in the outer radiation belt seemed to correspond to aurora electron fluxes. The first measurements radiation intensity fluctuations in the lower belts /2I/ demonstrated that these correlate with solar, magnetic and ionospheric activity including aurorae. It seemed natural, that in course of geomagnetic disturbances, when the general pattern of the geomagnetic field is altered, the particles are able to leave the radiation belts. ~~Subsiding~~ Penetrating into denser earth atmosphere layers they could cause aurorae /II/ and sporadic ionisation in the ionosphere. Therefore at first radiation belts due to ~~xxxix~~ various qualitative ideas, were considered to be a natural source of aurorae . Then there appeared theories , which connected the outer radiation belts formation with solar corpuscular fluxes, I.S. Shklovsky et al /II/, Beas and Baid /22/,

S.B.Pikelner /23/, Gold /24/. Though these authors differently treated the problems of particles and plasma clouds consisting of solar corpuscular fluxes trapped by the geomagnetic field, they left unsolved another important problem - energy transfer from slow ions of corpuscular fluxes to fast electrons of the radiation belts.

Further investigations concerned not only theoretical research: specification of the particle trapping and accelration mechanism on the one hand, and on the other - finding out the mechanism of particles loss from the belts and the particles life time, but also an accumulation of experimental data of the spectrum and intensity of a particles at ~~xxxxx~~ various altitudes, angular distribution of their velocities, variation with time and correlation with different phenomena. Let us consider these works in detail.

Considerable variations of particle fluxes intensity in the belts during geomagnetic storms are one of the most striking display of close connection of the radiation belts and geomagnetic field. Rothwell's et al./25/ investigations on Explorer IV and Arnoldy's et al /26/ investigations on Explorer XI convincingly showed, that in the course of a geomagnetic storm development radiation in the belts considerably decreased and after the storm it is not only restored but it became more intensive than before the storm. During the storm the outer radiation belt profile and dimensions are changed as well as the energy spectrum of the particles, ~~whi~~ which ~~duringxxthexstorm~~ became more rigid, during the storm.

All this points to the complication of the mechanisms of loss and replenishment of particles of the belts. Alongside the discussion of possibility to replenish the outer belt due to solar corpuscular fluxes, in /26/ there was made a suggestion, that particle flux variations in the belt could be connected with variation of atmosphere density at high altitudes during geomagnetic storms, when some processes, accelerating the particles in the atmosphere are intensified. The fact that the upper atmosphere density is controlled by the solar activity /27,28,29,30/, can also give an explanation to the observed in the outer zone radiation intensity variation with solar activity.

When the position of the radiation belts in the earth magnetic field was investigated precisely it was revealed, that magnetic lines of force, going out of the outer radiation belt, reached the latitudes, which did not coincide with aurora regions, the most striking difference was marked in the ~~Southe~~ Southern hemisphere. Thus, only the outmost parts of the radiation belts are able to provide particles to excite aurorae. Certain difficulties arise when one tries to explain aurorae excitation due to ~~in the belts during geomagnetic storms are one of the most striking display of close connection of the radiation belts and geomagnetic field. Results of /25/ investigations on Explorer IV and~~ the particle loss from ~~of~~ the outer belt, as it should be assumed that there is p particles transition from the central part of the zone to

the outer one. Meanwhile Argus experiments showed, that trapped particle shells appeared to be very stable in time, and particles transmission from one magnetic shell into another one with another geomagnetic latitude is not observed.

The basic assumption, that the intensity and spectrum particles in the radiation belts correspond to the intensity spectrum particles of aurorae, was also tested experimentally. Here, it was important to compare corpuscular fluxes measurements, carried out by rockets, at about 100 km altitude with those of the radiation belts, particularly of their lower part. Let's consider this problem in detail, as it is of principle importance for the theory, which could give an explanation to the excitation of aurorae glow and ionosphere ionisation.

Experimental data Concerning Corpuscules in the Ionosphere and in Aurorae

Though many experiments were carried out on rockets and satellites, instrumented for penetrating radiation measurement, at present only few data of the intensity and energy spectrum of the corpuscular radiation, penetrating the ionosphere are available. This fact is connected with the following: when the earth radiation belts were discovered all the attention was drawn to the investigation of the maxima of the belts and finding their outer boundaries, because these data were of great importance for estimating radiation hazard for space flights (compare /36/). In the present survey on the contrary we are interested in the lowest part of the radiation zones, penetrating into the ionosphere and interacting with it. The ionosphere and aurorae are situated considerably lower than the belt maximum, which is situated at about 3000-4000 km altitude above the equator, and in the high latitudes - lowers up to $\sim$500 km.

Van Allen and his collaborators were the first who by means of rockets in 1953 found corpuscular radiation in the upper atmosphere at comparatively low altitudes ($\sim$100 km). Penetrating radiation was recorded by means of relatively thick-walled (0.1 - 0.4 g/cm^2). Geiger counters at the $\sim$ 50 km altitude in the polar region by Meredith, McDonald, Ellis, Van Allen al./37,38,39/. The authors beleived that there were recorded only electrons with the energy of $>$1 Mev their flux being (according to the isotropic assumption) $\sim$ 10 - 20 electrons/cm^{2}sec. These results were confirmed by the data, obtained with the use of a scintillation counter /42/. At low altitude of about 50 km corpuscules effect only slightly contributed to the cosmic ray background, but at the 100 km altitude a thin - walled counter recorded radiation 5 times as intensive, as cosmic rays. The investigations of 1953-1955 showed that the corpuscular radiation fluctuates with time very much, it has clearly pronounced latitudinal variations with their maximum at the geomagnetic latitude 65-70°, i.e. coincide with the maximum zone of aurorae. This proved that corpuscules had electic charge.

Further investigations by Van Allen carried out by means of scintillation counters /43,44,45/ showed that the primary corpuscular radiation consisted of electrons with the energy, mainly, 10-100 kev (at least $<$200 kev). In the corpuscular radiation zone maximum the electron flux was 10^6-10^8 electrons/cm^{2}sec (energy flux .1-0.01 erg/cm^{2}sec.), these electrons decelerate at the 90-110 km altitudes, and produce bremstrahlung X-ray radiation with the intensity of 10^3 - 10^5 cm^{-2}sec^{-1} reaching the altitudes of about 50 km, and sometimes up to 25 km /46/. L.A.Antonova's et al./47,48/ reported, that a flux of electrons of 1-5.10^{-2} erg/cm^{2}sec steradians, the energy spectrum maximum of which being equal to 10-40 kev, was recorded by means of fluorescent screens with phosphor ZnS(Ag) at the 70-100 km altitudes in the middle latitudes and in the polar region. These results were recently confirmed by T.M.Kasatschevskaja et. al /49), who made measurements at the same altitudes using some other method: thermoluminescent phosphor Ca SO_4 (Mn). In /44/ it was indicated, that corpuscular flux intensity at the period of the maximum solar activity in 1957 was 3 times of that in 1953-55.

All these experiments, carried out on rockets probably point out that at the 70-100 km altitude there is a permanent electron flux with effective energy - 20-50 kev. The electron flux appreciably fluctuates in time, its variation being probably I-2 order of magnetude. The energy of the flux comes to a considerable value - about 10^{-2} erg/cm^2 sec. steradians, and in the geomagnetic latitude 67^0 it reaches its maximum about I - 0.I erg/cm^2 sec. sterad.

Considerable variation with latitude of the measured corpuscular flux intensity with a sharp maximum at 67^0 of the geomagnetic latitude, lying in the auroral zones (similar results were obtained for the Southern polar region /45/), and high intensity of the radiation, comparable with the energy which aurorae emitted in the visual part of the spectrum made Van Allen believe, that it is the corpuscular radiation that causes aurorae and it is somehow connected with them.

Aurorae Electron Fluxes Measurements by Means of Rockets and Satellites

Intensive corpuscular fluxes /44/, penetrating extremely deep into the atmosphere 745/ were recorded by the rocket fired on I4.VIII-57 into the luminous features of the aurorae.

Then several rockets have been fired into luminous features of aurorae to measure the primary corpuscular flux and its spectrum. The results of ion and electron fluxes measurements in diffusive aurorae forms of intensity class I, carried out on the rocket launched on February 2I, I958 and in the active arc of the aurorae - on February 25, I958, were reported in McIlwain's papers /50,5I/. Corpuscules with the

energy ~I7 - 20 kev were recorded by means of a scintillation counter with scintillator CsI, in front of which electromagnetic spectral analyser were installed. Electrons were first recorded at the 80 km altitude(the flux was 0.I erg/cm^2 sec sterad) and at the maximum altitude of I20 km the flux was $1.6 \cdot 10^{10}$ electrons/cm^{2}sec. The main part of the energy falls on soft electrons with the energy < 10 kev. Electrons energy spectrum in the energy region of 3-30 kev was equal to $2.5 \cdot 10^9 e^{-E/5\,keV}$ electrons/cm^{2}sec, and the total energy flux is about 20 erg/cm^{2}sec in the diffusive glow. Besides there was recorded a flux of protons of 80-250 km kev with the following spectrum: $j(>E) = 2.5 \cdot 10^6 \exp\left\{-E/30\ \text{kev}\right\}$ protons/cm^{2}sec sterad. and with the total flux $\sim 1.5 \cdot 10^7$ protons/cm^{2}sec. Almost monoenergetic electrons flux with the energy about 6 kev and with the maximum flux about $5 \cdot 10^{10}$ electrons/cm^{2}sec steard (~ 2000 erg/cm^{2}sec) /5I/ was recorded in the active arc of aurora. Efficiency of electrons energy conversion in light energy emission in the atmosphere is about 0.2 per.cent. This important coefficient makes it possible to estimate electron flux in various aurorae occurences according to visual estimate of their intensity.

Papers by Meredith et al /52, 53/ inform of three rocket launchings into the luminous aurorae arcs on January 25, March I5 and 22, I958. Geiger counters, proportinal, impulse and scintillation counters were installed on the rockets. That allowed to measure not only a flux of corpuscules but also their energy spectrum.

When the rocket passed through luminous formations of aurorae a flux (up to 5 erg/cm^{2}sec) of comparatively soft electrons with the energy above 3 kev was recorded. Some data about electrons energy spectrum were obtained in the work: an electron flux with the energy $\geqslant 8$ kev was 10 times as intense as an electron flux with the energy above 35 kev. Besides, here as well as in /50,51/ there was recorded an ion flux of $\sim 10^5$ particles/cm^{2}sec sterad. the energy flux of which was by 2 orders of magnitude less than that of the electron flux. At the altitudes below 130 - 140 km there was observed the decrease of ion and electron fluxes and ~~violation~~ distortion of isotropic angular distribution of particle velocity. It was noticed, that the electron flux above 140 km was not constant and in one of the experiments, had 3 maxima corresponding to 3 moments when the rocket got into auroral rays. Contrary to electrons which were ~~is~~ not observed outside the regions of auroral display, ions were found in the upper layers irrespective of aurorae. It is of importance to mark, that up to the 178 km altitude electrons with small energy of 30-1000 ev within the accuracy of 10^9cm^{-2}sec^{-1}sterad^{-1} have not been found.

An interesting result has been obtained on Explorer XII /54/. ~~where~~ At the 1000 km altitude, when the satellite was passing just above the auroral arc (if the satellite trajectory is projected along the magnetic line of force) there was recorded an extremely powerful corpuscular radiation flux ($\geqslant 10^4$erg/cm^{2}sec.

The recorded corpuscular radiation, as well as in auroral regions, was unusually soft (the ratio $j(>30$ kev$)/$ $/j\ (>70$ kev$)$ was 27:1 instead of usual 14:1). Angular distribution of particles velocity was such, that the majority of the particles should have been absorbed in the atmosphere after several hundreds of oscillations (for about a few tens of minutes). Intensive corpuscular flux was also observed, when the satellite was passing above a long and wide auroral arc glowing in the line 6300 Å, the corpuscular radiation intensity decreasing in time in course of the aurora glow dying away.

Recently on Explorer XII and Injune I O'Brain et al /55,56,57/ obtained new important data about trapped particles flux and spectrum in the lower and central parts of the radiation belts. Earlier electron flux values 10^{11} cm^{-2}sec^{-1}(E >20 kev) for the outer radiation belts appeared to be highly overestimated. The most recent data about the electron flux j measurements on Explorer XII are and spectrum according to the At hight ~1000 km according to the measurements on Injune I an electron flux with E $\geqslant 40$ kev comprises $j = 10^6$cm^{-2}sec^{-1} and according to one scintillation counter measurements the total energy flux for E $\geqslant 1$ kev is equal to ~ 10 erg/cm^{2}sec. sterad., and according to another one - ~ 70 erg/cm^{2}sec, sterad. ~~a-ae~~ listed in the following ~~Table~~ Table.

Table 1.

E kev	$\geqslant 40$	45-60	80-110	110-1600	1600-5000	5000
j cm^{-2}sec^{-1}	$\sim 10^8$	9.10^7	8.10^7	$< 10^8$	2.10^5	$< 10^3$

In those fluxes was such small pitch angles values ~~are true~~, that the majority of those electrons should pass from the I000km altitude to $\leq$ 200 km , and being there obsorbed, they cause an aurora. It is likely, that it was those fluxes with which one connected the observed during IGY almost continuous deffusive aurora, glowing on the whole sky /5/. The value varies considerably with time and geomagnetic latitude, forming a wide peak at $\varphi_m \approx 50^\circ$ and in the auroral zone. At higher altitudes the spectrum of electrons is as a rule steeper, i.e. here in the electron flux there predominate softer corpuscules. In auroral zones j varies for a few seconds by an order of magnetude, what corresponds to the distance of several tens of km covered by the satellites. It is appropriate to remind that the first investigations of soft corpuscular radiation carried out by Krassovski et.al /58,I9, 20/ on the 3d Soviet Satellite by means of a luminescent detector, revealed just the same peculiarities of corpuscular radiation.

The most suitable instrument, which has been used up till now, and intended for corpuscular radiation studies, is a luminiscent screen combined with photomultiplier, described by Krassovski, Kushner, and Bordovsky /59/. Measurements with the help of fluorescent screen, made out of ZnS(Ag), which was particularly sensitive to soft electrons were carried out on the 3d Soviet Satellite, where there were obtained valuable results, though satisfactory measurements

were very few (only one revolution on May I5, I958), because of the instruments almost all the time were scaled off (60, 58, I9 20/. The threshold of the instrument sensitivity to the electrons ($\sim$ Io kev) was the lowest of all used before. The lowest intensity has been recorded above the geomagnetic equator in the inner radiation belt at the I300 km altitude (in the Eastern Hemisphere). If the energy of electrons was about 20 kev, their flux was 10^{-14}a/cm^{2}sterad = 6.10^4 electsons/cm^{2}sec sterad /I9/. On May I5 at night the 3d Satellite passed above the Pacific Ocean at the I720-I880 km altitude 42-54°S. There was detected both electron intensity and energy variation in the flux with the Satellite revolution and geophysical latitude and very quick ($\sim$I sec /60/) ~~temporal~~ intensity variations in time by an order of magnitude. Near the equator the electron energy was $\sim$ 40 kev and in the polar region - it fell up to I0 kev. These experiments revealed, that particles movement direction is normal to magnetic lines of force, what indicates that the particles move along spirials round lines of force. Later disclike distributions of particles velocities was confirmed by Van Allen et. al /I6/ and Holly et. al /6I/. The minimum flux recorded in those experiments at low altitudes was equal to about I erg/cm^{2}sec. But the value was much higher that the particles fluxes, recorded by another methods. These experiments obviously show, that soft electrons possesses the major part of the energy both in the inner and outer radiation belts. In /60,58,I9,20/ there were put forward some considerations concerning great geophysical importance of ~~these~~ electron fluxes, capable to induce appriciable heating of the upper earth atmosphere, providing a sharp temperature gradient with height and detected by Satellites atmospheric expansion in the polar regions, where flux intensity was higher.

Futher investigations confirmed, that the fundamental part of energy in the radiation belts is carried by electrons.

According to new data /56/, electron flux with $E \geq I$ kev is about IO^{10} erg/cm^2 sec sterad, the pitch angles between electron velocities and a magnetic line of force being so small that the majority of electrons should reach the ~ 200 km altitudes and cause aurora. Detailed ~~Analogous~~ investigations of angular electrons distribution /57/ indicate, that in various latitudes electron flux with $E > 40$ kev, penetrating the atmosphere, is $\sim IO^4$ cm^{-2}sec^{-I} sterad^{-I}. and total flux of electrons dumped into the atmosphere in the day-time is about IO erg/cm^2 sec /56/.

The problem of Corpuscular Acceleration in the Atmosphere

The obtained results are of principle importance, as they consider the problem of corpuscular origin, auroral and radiation belts particles origin in a new way. Continuous powful particle fluxes at appriciably low altitudes directed into the atmosphere, and observed in the atmosphere cannot be the result of the trapped particles loss from the belts. Therefore papers /56, 57/ indicated that it is necessary to assume that there exists a mechanism of their acceleration, located in the ionosphere. Probably the radiation belts are formed under the influence of the same mechanism, when the accelerated electrons enter the magnetic trap trajectory. Earlier Krassovski et.al /58,62/ in connection with the data obtained on the 3d Soviet Artificial Satellite made some consideration concerning soft particles acceleration in the earth magnetic field. Recently by means of the 2d spaceship Vernov et.al /63/ found considerable corpuscular fluxes in the atmosphere and also at the low altitude of 320 km, and declared for the hypothesis of electron local acceleration within the limits of the geomagnetic field.

The hypothesis about particles acceleration in the earth atmosphere caused by one or another process was considered by a number of authors (Alfven, Hoyl, Lebedinski) who tried to give an explanation to aurorae earlier /3/. Pan /64/ and Reid /65/ It was ~~mainly~~ considered mechanisms of electron acceleration by hypothetical local electric fields in the ionosphere, the existence of which is believed to be highly presumable, Kellogg /66/ assumed that while deffusing in the geomagnetic field, particles accelerate. Obayashi /67/ considered Fermi acceleration mechanism to be due to hydromagnetic waves. The hypothesis of particles acceleration in the static magnetic field like in an original geocyclotrone, was suggested by Helliwell and Bell /68/. Coleman /69/ considered the effect of inhomogeneous gradually changing geomagnetic field and betatron mechanism of acceleration. Dessler, Hanson /70/ suggested an acceleration mechanism by a shock wave which is produced by a solar plasma entering the earth magnetic field. Singer /7I/, Chamberlain /72/, Chamberlain et.al /73/ stated that it is ~~xxxx~~ necessary to assume that in the earth atmosphere there exists particles acceleration. A transresonant electron acceleration mechanism in the outer part of ionosphere by whistlers was suggested by Parker /74/. Akasofu and Chapman /76,75/ made an attempt to connect geomagnetic ~~variations~~ disturbances, the radiation belts ~~xx~~ and the ring current. And they obtained original angular distribution of trapped particles velocity.

L.A. Antonova and Ivanov-Kholodny in papers /77,47,78/ proceeding from the hypothesis that there are corpuscular fluxes in the ionosphere, calculated energy spectrum of electrons producing night ionosphere ionisation. Rather low electron energy ($\gtrsim$ I00 --200 ev) and steep electron spectrum $dN(E) \propto E^{-\gamma} dE$, where γ =4.5 were obtained. Vernov et al. ucaxe on „Mechta" γ=5[99]. Various observational data of the spectrum and the calculated spectrum for a quiet ionosphere are compared in Fig.I. These calculations can be carried out if it is assumed that ~~xxx~~ there is an isotropic electron

velocity distribution in the space. The measurements indicated that there is no isotropy. Taking into account the true velocity distribution one can obtain a variation of the calculated electron energy spectrum as well as another lower boundary spectrum value though the total electrons flux energy value about 1 erg/km²sec is preserved. One of the displays of the corpuscular electron fluxes is X-ray radiation recorded on balloons. Let us consider experimental data concerning this radiation.

X-Ray in the Upper Atmosphere

Secondary X-ray produced by electrons penetrate deep into the atmosphere up to low altitudes, and this fact makes it possible easily to carry out investigations over a long period of time with the help of balloons. Intensive X-rays event at the level, characterized by the atmosphere depth of 8 g/cm^2 (32km) has been recorded by Winckler and Peterson /79/ during one of the most intensive aurorae. X-rays intensity with quantum energy 50-80 kev reached 5 mr/h, i.e. 4.I0^4 photons/cm^{2}sec (compare /80/). Mechanism of electron ~~radiation~~ deceleration resulting from passing through comparatively dense atmosphere layers was considered by Kellogg /8I/, who indicated that when the electron energy is about 50 kev one quantum of X-rays is produced on the average per I0^4 electrons, and as for more energetic electrons the efficiency is higher. According to /82/ the efficiency for electrons with 300 kev energy is equal to 400 electrons/quant. Thus on the base of the observed X-ray flux value one might expect that there are extremely intensive electrons fluxes about 3.10^{8} particles/cm^{2}sec in aurorae, what is in agreement with results of direct rocket measurements of the fluxes.

Rather intensive X-ray from aurora, passing through the zenith was observed by Winkler 23.IX.57 /83/ by means of an ionization chamber, installed in the balloon. Winckler estimated an electron flux, producing the observed X-rays of 8.10^{9} electrons/cm^{2}sec ($\sim 10^3$erg/cm^{2}sec) assuming that electron energy was about 100 kev. In the same work it is reported that a flux 50 times as intensive was observed on 13.IX.57. These values are somewhat overestimated, what is connected with some simplifications in calculations, in particular with the lack of precise values of energy spectrum of electrons.

In more recent years Winckler, Anderson, Peterson, Arnoldy et.al carried out numerous experiments with the help of balloons /82,84,85,46,86,87,/. Summarized results of those works are given by Anderson /88/ and Winckler /83/.

The most intensive X-ray fluxes are observed during aurorae /37,43,79,85,86/, and during severe geomagnetic storms /84/. Sporadic X-ray has been observed for several hours with characteristic sharp and rapid intensity fluctuations.

During the magnetic storm on 29.VIII.57 Anderson /82,84/ recorded a flux of X-ray photons ~ 20 photon/cm^{2}sec sterad. with the energy of 100 kev at the altitude characterizing residual atmosphere 11 g/cm^2. Consequently, taking into account absorption beyond the atmosphere ~~limits~~ the flux should be about 75 photons/ /cm^{2}sec sterad. Thus an electron flux beyond the dense atmosphere layers was estimated (at about 100 km altitudes) to be 6.10^{5} electrons/cm^2 sec.sterad. (~ 0.2 erg/cm^2 and even more, if the

assumed electrons were "softer" than 300 kev). It is clear that even assuming the comparatively high electron rigidity (see above) rather intensive corpuscular radiation fluxes in the upper atmosphere are obtained, though they are less intensive, than during bright aurorae. It is pointed out in /82, 84/ that the fluxes like in case of an aurora are of highly limited local ~~special and temporal~~ pattern, in space and time.
It is of importance to note that often the radiation was not connected with either geomagnetic or solar phenomena. Anderson /88/ indicated that usually X-rays decrease after sunset though it is rather a rule than a law. It was reported, that close to the magnetic pole no X-ray has ever been observed, even during geomagnetic disturbances.

Let us consider in detail X-ray observation results when there are no aurorae and magnetic storms.

During "quiet" periods of time in the polar region X-rays were observed for 30 per cent of the total time of balloons flights /87,88/, though the radiation intensity was 10-100 times less, than during aurorae. The above mentioned radiation was recorded by means of Geiger counters, ionization chamber, and as a result of these experiments differentiational photons spectrum was drawn up, which apparently was a reflection of the energetic electrons spectrum causing the radiation somewhere at the $\sim$I00 km altitudes.

In order to calculate with sufficient reliability according to the observed X-rays the electron flux causing the latter, it is necessary to know this radiation spectrum. Numerous spectrum measurements made by means of scintillation counters in the polar region were reported by Anderson /87,88/. The measurements were carried out in three spectrum regions 45- 95, 95 - I70, and I7o - 340 kev. Taking into account the absorption effect in the atmosphere three typical spectra given in /87, 88/ are well approximated by the formulae $dn(t) = \kappa E^{-\gamma} dt$

where $\gamma = 2.3 \div 2.8$ (see Fig.1).

In I954-I957 X-rays spectrum beyond the auroral zone in the energy region of 200-I000 kev was also measured by Kupperian and Friedman /89/ with the help of scintillation counters, installed in rockets at the 23-II4 km altitude. It was found out that with increase of height progressive increase of soft quanta intensity and decrease of rigid quanta intensity occurred in such a way that the total number of quanta remained approximately constant. Those detailed spectrum measurements data at the 42-57, 66-75, and II0-II4 km altitudes which give coinciding results in the energy region of 5o-300 kev, are given in Fig.I. For I00-300 kev energy these results coincide with Anderson's measurements data /87,88/ however in the region of $E < 50$ kev. they are not in agreement. Probably the data /88/, obtained in the polar region in the period of X-ray increase, reflected a peculiarity of the phenomenon, during which there occurs an additional intensity increase of particularly soft radiation.

It should be taken into account, that in the region of I00 -300 kev the data /88/ are by an order of magnetude higher, than those of /89/.

Thus, the abovementioned experiments show, that there is considerable X-ray radiation, the intensity of which greatly increases towards the small energies about I0-20 kev, in the upper atmosphere. These fluxes become more intensive during auroral and geomagnetic storms. Comparing those data with rocket observations of electron fluxes at the I00 km altitude it is easy to come to the conclusion that in the atmosphere there exists permanently sufficiantly intensive electron flux which reveals itself particularly due to decceleration electron radiation when they penetrate into relatively dense atmosphere layers at the ~ I00 km altitude.

Corpuscular flux intensity

The first corpuscular radiation data in the low parts of the radiation belts, were obtained by means of Geiger counters, designated ~~meat~~ for investigation of cosmic rays and therefore they were not ~~sensitive~~ to comparatively soft radiation being, as it was later found out the fudermental part of corpuscular radiation. ~~The~~ ~~The~~refore the first observations gave underestimated values of intensity and overestimated values of particles effective energy, and at high altitudes the instruments scaled off both in the first American and Soviet satellites.

It has been already mentioned, that earlier electron flux intensity determinations were overestimated. According to Table I (p.I2) the elctron flux with energy $E>40$ kev is about I0 erg/cm^2 sec. And the ~~fluxxpxxxx~~ loss of energy of the flux totals only a nigligible part. It is obvious that the flux energy is not sufficient to cause not only intensive aurorae, where electron fluxes with power of hundreds and thousands of erg/cm^{2}sec could be observed, but even weak ones, as here electron flux low rate is I-I0 erg/cm^{2}sec. So, according to O'Brien's et.al observation /56,57/ at the I000 km altitude in an auroral zone electron fluxes with $E>I$ kev reach I0-I00 erg/cm^{2}sec. and considerable per cent of electrons penetrate into the atmosphere, producing ionization and excitation of atmosphere species at the I00-200 km altitudes. However these ~~gxx~~ general fluxes could not excite

an aurora, as when the coefficient of coversion of electron flux energy into radiation is about 0.2 per cent (compare with p.I2) they produce about 0.02-0.oo2 erg/cm^{2}sec, what practically is next to impossible to observe at the nightglow background.

On the other hand, investigations of elementary processes in the ionosphere /77,78,90,9I/ make it necessary to assume, that in the upper atmosphere there exist electron fluxes of about I erg/cm^{2}sec.

Summarizing various experimental data concerning electron fluxes in the ionosphere and aurorae at the I00-I000 km altitudes, let us emphasize some peculiarities of the fluxes, which are applied to the problem: from what regions electron fluxes originate.

Are the radiation belts particles the sourse of aurorae?

Experiments showed, that magnetic lines of force from the outer radiation belts approach the latitudes, situated below auroral zones, while corpuscular fluxes intensity maximum coincides with auroral zone at the altitude of I00 km. As a result of investigations on rockets and satellites it was established, that in the ionosphere regions during quiet periods corpuscular fluxes, comparable from the intensity point of view with electron fluxes in the radiation ~~xxixt~~ belts are observed. Not to mention highly intensive electron fluxes, causing aurorae one may say that the radiation belts, if we take into account their energy store, are unable to supply even these general electron fluxes in the ionosphere, as electron fluxes in the radiation belts are comaprably stable, at least they gradually vary, long-lived and hardly spending their energy. At the same time in the ionosphere below the radiation belts there exist comparatively rapidly varying, local electron fluxes, with considerable loss of energy particularly in the auroral zone. Besides present data testify to the fact that electrons energies spectrum in the radiation belts is probably more rigid and more sloping, than in corpuscular fluxes in the iononsphere and aurorae, in connection with it the latter are absorbed at the 200-300 km altitude (ionosphere) and ~ 100 km (aurorae) while particles from the radiation belts are able to penetrate up to D-layer and should cause ionisation and (as a result) radio-wave absorption. It should be noted, that particle fluxes , which cause aurorae, posess, such great energy that the notion of the geomagnetic dipole field is not ~~the~~ true for them. In this connection , the fact ~~that~~ of coincidence of geomagnetic latitudes and aurorae occurrence moments in the both hemispheres, revealed during IGY, needs special explanation. However at present this fact is disputed.

There can be presented some other arguments against the mechanism of formation of electron fluxes, causing aurorae, out of the radiation belts particles but the abovementioned arguments are probably enough. It is worth adding that the discussed in literature mechanisms of particles loss from the

radiation belts cannot provide a formation of necessary intensive electron fluxes.

Mechanism of Electron Loss from the Radiation Belts

Perhaps, one of the most important problems, to which the theory explaining aurorae by particles of the radiation belts should give an answer, is the problem concerning the way of particles leaving the radiation belts for the atmosphere. As it was mentioned above, favourable conditions for particles loss from the radiation belts arise perhaps in the period of geomagnetic disturbances. There were also suggested another mechanisms of particles loss.Rode /85/, Singer /7/, Inoue et.al /92/ estimated the velocity of the loss due to the impact of particles from the belts with atmosphere particles. A charged particle of the radiation belts has the greatest probability of impact close to the turningepoints where almost every impact leads to the increase of the pitbh angle and consequently quickens the particle loss due to absorption in the atmosphere. However this mechanism is rather slow. V.D.Pletnev /93,94/ considered a particle loss due to short--period geomagnetic field variations. At different distances from the Earth there originate regions of lower intesity of the trapped particles flux, these distances corresponding to the observed data.

Matsushita /95 , 93/ considered a mechanism of electron loss under the ifluence of electrostatic fields, formed in the upper atmosphere during geomagnetic storms. Events like ionisation increase in F-layer, appearence of E_s, increase of fE_1 and increase of absorption of cosmic radio ~~emission~~ noise in the ionosphere D-layer he connected with penetration of electrons from radiation zones into the atmosphere /90/.

Kern and Vestin /97/ considered particles loss from the belts resulting from instability in the electron belts due to ~~xxx~~ certain lowering of turning-points ~~at the trapped points~~, though the reason for the lowering is still unexplained. As we saw, the discussed mechanisms are not able to give an explanation to the formation of intensive, local rapidly varying soft electron fluxes. The results of investigations of ~~th~~ the radiation belts and auroral particles discussed in the given survey show that the radiation belts are unlike to be the source of aurorae. And again there arises a question concerning the source of aurorae. Probably soft electron fluxes quickly loosing their energy, exciting aurorae and the ionosphere are formed in the upperest atmosphere itself at relatively low altitudes One may believe /77,78/, that electron acceleration results from geomagnetic variations due to the earth magnetic field. However, as it is clear, at present the concrete mechanism of these electrons acceleration has not yet found.

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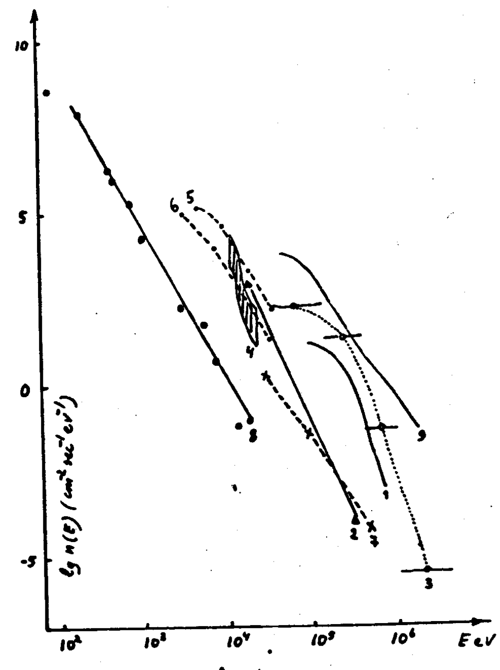

fig. 1

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Legend to Fig.I

Fig.I. Energy spectra of electrons:
(I) from data by Cladis et. al. /98/
(2) meand spectrum, computed by Anderson from X "Bremsatr". /88/
(3) from data by Holly and Johnson /6I/ (in relative units)
(4) from data by V.IKrassovski et al. /20/
(5) from data by McIlwain /5I/
(6) from data by Meredith et al. /52/
(7) computed from data by Kupperian and Friedman /89/
(8) computed /78/
(9) from data by O'Brien et al. /55/

HYDROXYL EMISSION IN THE UPPER ATMOSPHERE

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Summary

The excessively high rotational temperature of the OH bands shows that there is no thermodynamic equilibrium between the rotational OH states and the ambient medium. Owing to different conditions of deactivation the rotational temperature of the hydroxyl with a low vibrational excitation is inferior to that of the hydroxyl with a high vibrational excitation. The relative and absolute populations of the OH vibrational levels are not constant which points to variations either in the height or in the processes involved in the appearance of excited hydroxyl. The number of newly formed hydroxyl molecules is compared only to the number of oxygen molecules dissociated by radiation in the Runge - Schumann bands below the 50 km level. The hydroxyl emission occurs at a height about 80-90 km where the number of dissociated oxygen molecules is less than the number of newly formed hydroxyl molecules. For a mutual equilibrium between these processes the region of the appearance of hydroxyl emission must take in either a high quantity of ozone from below or great quantities of atomic oxygen originating in the upper regions due to the photodissociation of ozone which

penetrated there from below. The ozone-hydrogen reactions of atomic hydrogen which,probably, have no existence in reality. It may be that the vibrationally excited oxygen molecules are produced in the region of the appearance of the hydroxyl emission due to the penetration of atomic oxygen to this region from above during a vertical mixing in the atmosphere. Such excited molecules can exist for a long time only with a low concentration of atomic oxygen. They can be deactivated as the result of the atom-exchange reactions with the molecules of the non-exited hydroxyl. Thus, the hydroxyl emission can be produced in the absence of atomic hydrogen. Various reactions with the participation of vibrationally excited oxygen molecules may give rise to a number of emissions in the upper atmosphere.

The problem of the origin of emissions in the upper atmosphere,among them the hydroxyl emission,has not yet been finally settled. The main obstacle to this is the absence of accurate values of constants for all possible elementary processes. This accounts for the fact that it is not always possible to proceed from qualitative evaluations of different reactions to their accurate quantitative analysis. Recently, however, there has been accumulated much observational material on the emissions in the upper atmosphere,which is very useful in clearing up some uncertainties in out former suppositions. Before proceeding to an analysis of the mechanisms underlying the appearance and variations of emissions in the upper atmosphere, we shall make a brief up-to-date survey over the basic factual data which have become available after the recent study of all the observational material accumulated in the USSR lately.

The rotational temperature of the OH bands from the 3,4 and 5th vibrational levels varies from 150 to 270°K. It is about 10° degrees higher for the 4th than for the 5th and for the 3rd than for the 4th level. The rotational temperature of the OH bands from the 6, 7, 8 and 9th vibrational levels is on the average higher and varies in the range from 150 to 350°K. The higher the vibrational level of the band, the higher the rotational temperature. On the average, in the case of a very high rotational temperature there exists a trend towards an increase in the OH band intensity with temperature. This trend is especially noticeable in the bands from the 6, 7, 8 and 9th vibrational levels in high-latitude (60°) areas. The same trend, in a milder form, can also be observed at middle latitudes (50-45°), though sometimes it is absent, especially with low rotational temperatures. The OH intensity and rotational temperature may often vary for tens of °K even during a single night. Such variations may take place in any season. However, the maximum intensities and rotational temperatures are typical of winter rather than summer time. All this is

especially apparent in the case of the bands from the 6, 7, 8 and 9th rather than the 3, 4 and 5th levels. At middle latitudes the seasonal variations are sometimes quite insignificant. The relative population of the upper and lower levels is not constant and is not always subject to approximation according to Bolzman's distribution. The relative populations of the 6, 7, 8 and 9th levels with respect to those of the 3, 4 and 5th levels display a trend towards increasing with rotational temperature for the bands from high levels.

The scatteting of the values of the relative populations of the 6, 7, 8 and 9th levels with respect to those of the 3, 4 and 5th levels decreases with an increase in the rotational temperature for the respective bands. The intensity of the molecular oxygen electronic band at about 8600 Å is in distinct correlation with the OH band intensity. Apparently, a similar picture is observed in the case of Hersberg's bands. There is a correlation between the 8600 Å oxygen band temperature and the rotational temperature of the OH bands from higher rotational levels. The latter, however, especially for high values, is greater than that of the 8600 Å oxygen band. The intensity of this band shows a trend towards increasing with rotational temperature, especially for the OH bands with a high vibrational excitation. There is a good correlation between the OH band intensity and the Na and H_α night-time emissions. A tendency towards a similar dependence is observed also in the case of the 6300 Å [OI] emission, when its intensity is small and there is no magnetic perturbation or aurorae. The scattering of the [OI] 5577 Å emission values increases with rotational temperature for the OH bands from high vibrational levels. On the average, it is always possible to observe some general trend in connection with the OH, O_2, Na, [OI] 6300 Å and even [OI] 5577 Å and the continuum intensities.

As the hydroxyl emission takes place in separate elementary layers of the atmosphere, which differ in temperature, the rotational temperature measured is, as shown by Shefov, the weighted mean of the concentration of the radiating hydroxyl molecules in those elementary layers (1).[x] As a result, if there is a temperature gradient in the region of appearance of hydroxyl emission, the measured rotational temperature will be below some individual values in the region. According to the rocket research data (2,3) the hydroxyl emission takes place

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x) A departure of the rotational OH states from Bolzman's distribution may become practically noticeable only over lines with $K > 6$. However, all published data for the rotational temperature were obtained over $K \leqslant 6$ lines.

at the height between 70 and 110 km and especially about 80-90 km where the virtual ambient temperature is known to be less than the maximum possible rotational temperature for the OH vibrational bands from the 6, 7, 8 and 9th levels and, probably, even somewhat less than the rotational temperature of the OH vibrational bands from the lower levels. Consequently, the rotational temperature, as determined from the OH bands, fails to represent the virtual temperature of the atmosphere. This is possible only if the vibrationally excited hydroxyl is either deactivated by radiation or disappears in some chemical reactions after a few collisions with the molecules and atoms in the atmosphere, whose number is insufficient to make the rotational temperature of the radiating hydroxyl equivalent to the kinetic ambient temperature.

Table 1 presents at the beginning a supposed reaction of the chemical destruction of excited hydroxyl by some atom or molecule denoted through X. Given below are two conditions under which the OH rotational temperature will be higher than the ambient temperature. τ indicates the mean time of existence of the vibrationally excited hydroxyl, if it is subject to deactivation by radiation. We denote by a_0 the product of gasokinetic crossection of elastic collision by the mean velocity of the medium's molecules and by [M] - the total concentration of all molecules.

This time is approximately equal to 2.10^{-3} for the 9th vibrational level and is monotonously rising with the diminishing of the level number until its value is about 10^{-2} sec for the 1st level. (4). Under the most adverse conditions the reactions with the participation of excited products may take place at each collision of the respective reagents, i.e. at $a_1 \sim 10^{-10}$ cm^3 sec^{-1}. In this case, however, the rotational temperature of the newly formed hydroxyl molecules would be at its maximum. It would certainly fail to reflect the ambient temperature. In reality, when hydroxyl is at low vibrational levels for which the mean lifetime with optical deactivation is somewhat higher, the newly formed hydroxyl molecules are apparently subject to a number of collisions before their deactivation through radiation. In that case the rotational temperature is more or less close to the ambient temperature. Thus, a considerable departure of the rotational temperature from the ambient temperature will take place when the X concentration will be close to or less than $10^{-13}cm^{-3}$.

Table 1 presents the A, B, C, and D reactions whose effectiveness is not accurately known but which seem to be the only possible reactions of destruction of the newly formed vibrationally excited hydroxyl molecules in the region of their virtual appearance at a height about 30-90 km, where the X concentration approaches the above value of 10^{-13} cm^{-3}. Bracketed on the right side are the thermal

effects of the corresponding reactions, the non-excited hydroxyl being taken into account. From the viewpoint of conditions which are of interest to us, the A reaction is of no importance, as it may involve only the hydroxyl whose vibrational excitation is higher than the 9th ground state level, i.e. such hydroxyl which has practically no existence in the upper atmosphere. Nevertheless, this reaction may turn out to be rather important for the limitation of hydroxyl excitation above the 9th level in the lower dense layers of the atmosphere. The B and D reactions will interfere with the establishment of an equilibrium rotational temperature in the OH bands from the high initial levels. The B reaction will have some effect for the OH states at the 6,7, 8 and 9th levels, while the D reaction will have an additional effect for the OH state at the 7 and 8th levels. Simultaneously, all the said states will be subject to considerable quenching. The atom-exchange C reaction will be effective for hydroxyl no matter what its excitation is. It may interfere with the establishing of a complete thermodynamic equilibrium for the rotational states of the vibrationally excited hydroxyl at all its levels and account for an increase in the relative population of the lower vibrational levels. This reaction will cause the quenching of all excited OH states at low altitudes where the density of the atmosphere is high. An increase in the OH rotational temperature over the ambient temperature indicates that the excited hydroxyl appears in considerable amounts above 80 km, where the density of the oxygen and nitrogen molecules is close and inferior to $10^{-13}cm^{-3}$.

A variation in the virtual temperature of the atmosphere for some tens of K degrees at a height between 70 and 100 km during several hours is possible only if there is a considerable inflow of heat to this region. Thus, for example, in a layer about 10 km thick at the height of 80 km, where the concentration of molecules is close to $5.10^{14}cm^{-3}$, even in the absence of losses due to radiation and thermal conductivity, the temperature may rise by $10^{o}K$ during 2 hours only if there is an energy inflow as high as about 100 $erg\ cm^{-2}sec^{-1}$. It is quite obvious that no such thing is possible not only at night but also in the day time. Therefore, the observed rapid variations in the average rotational temperature for some OH bands may be taken only as evidence of variations in the height of the region of appearance of the hydroxyl emission.

As the region of appearance of the hydroxyl emission rises above the region of the temperature minimum at a height about 80 km, the deactivation of hydroxyl by radiation will increase due to a decrease in its deactivation by the chemical processes. In the meantime the relative population of the vibrational levels, especially that of the higher ones, will be less subject to variation due to the collision with the non-excited molecules in the atmosphere. The relative and absolute populations of the high vibrational

levels will go up. Simultaneously, the rotational temperature will rise, since the number of elastic collisions of the excited hydroxyl molecules until the latter are deactivated by radiation will become insufficient for the establishment of a thermodynamic equilibrium. All this provides a good explanation for the tendency of the effective vibrational temperature to increase with the rotational temperature, as can sometimes be observed.[x)]

However, the region of appearance of hydroxyl emission may also spread downwards from the minimum temperature region. The virtual temperature and density of the atmosphere increase with a decrease in height. In this case, the rotational temperature will also rise. But the relative population of the high vibrational levels will not increase, as their deactivation in the B and D reactions will grow less. The OH band intensity will not increase and will not depend on the rotational temperature.

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x) In view of the fact that the high rotational temperature fails to reflect the virtual ambient temperature, our former interpretation of such dependence as the result of a variation in the hydroxyl yield in the ozone-hydrogen reaction due to temperature variations in the reacting products proves untenable. (5)

The above described processes enable to provide, at least, a qualitative explanation for the observed laws which govern the rotational and vibrational temperature and the intensity of the OH bands in the atmosphere. A slight increase in the rotational temperature of hydroxyl with a decrease in its initial level, beginning with the 5th vibrational level, can be accounted for both by a more intensive generation of the low-excited hydroxyl at low altitudes and by the C reaction whose effectiveness tends to increase with a decrease in height due to a greater density of the atmosphere.

Most interesting is a enormous power of hydroxyl emission in the upper atmosphere. On the basis of numerous observational data related to the middle-latitude areas Shefov has determined the average intenities on the OH bands in the visible and the neighbouring infra-red region of the spectrum (6). If we proceed from Shefov's data and use interpolation, by taking into account only the linear members in the expression of the dipole momentum, to determine the intensity of the more infrared bands in the region inaccessible for observation, as was done, for example by Shklovsky (7) and in one of the versions by Heaps and Herzberg (4), we shall be able to obtain an approximate estimation of the average yield of the newly formed hydroxyl molecules, apart from the optical transitions from the higher states. It can be put at $10^{11} cm^{-2} sec^{-1}$ for each vibrational level

of the ground state, starting with the 9th level and downwards. Thus, it can be expected that the total number of the newly formed hydroxyl molecules in all vibrational levels will be as high as $10^{12} cm^{-2} sec^{-1}$.

If we assume that the formation of hydroxyl is the result of the ozone-hydrogen reaction proposed by Bates and Nicolet (8) and Herzberg (9), each hydroxyl molecule deactivated by radiation will enter into reaction with the atoms of oxygen. As a result of these two successive reactions the ozone molecule and the oxygen atom combine to form another oxygen molecule. No matter how rough are the above estimations, the full yield of the new oxygen molecules in the processes mentioned above can be estimated as equal, at any rate, to not less than $10^{12} O_2 cm^{-2} sec^{-1}$. However, in the region of appearance of the hydroxyl emission the sun's ultraviolet radiation fails to dissociate such a great number of oxygen molecules. Above the 100-km level the emission of the Runge-Schumann continuum is accountable, on the average, for a dissociation of about $2.10^{11} O_2 cm^{-2} sec^{-1}$. The emission in the Runge-Schumann bands is mainly absorbed below the 50 km level. This results in the appearance of the excited oxygen molecules which, on colliding with the non-excited oxygen molecules, give rise to an ozone molecule and an atom of oxygen. The total number of such acts is on the average equal to about $10^{12} cm^{-2} sec^{-1}$. The appearance of 10^{12} OH $cm^{-2} sec^{-1}$ indicates that the restoration of the oxygen molecules mainly takes place in the region of appearance of the hydroxyl emission at the heights between 80 and 90 km. This, however, is possible only if in this region, due to a vertical mixing in the atmosphere, the ozone from the underlying regions would come into contact with the atomic hydrogen and oxygen from the overlying regions. It is also necessary that there should be no other way available for the formation in substantial quantities of molecular oxygen from the atomic oxygen, due for example, by triple collisions with the participation of two atoms of oxygen, or in the collisions of the ozone molecules with either the ozone molecules or oxygen atoms.

The basic data for the ozone-hydrogen process are presented in Table 2. To enable this process to play an important role, it is necessary that the product of the ozone and atomic hydrogen concentrations was approximately equal to 10^{18} cm^{-6}. At the height of about 90 km, the concentration of atomic hydrogen does not exceed $3 \cdot 10^{6} H\ cm^{-3}$ (10). Since below 100 km the atmosphere is undoubtedly well mixed and has a uniform relative composition, the change of concentration of atomic hydrogen below 90 km for the height of the homogeneous atmosphere, even in a most favourable case, can hardly be greater than e - times. However, certain data at our disposal on the effective unification of hydrogen atoms with oxygen molecules in triple collisions with the formation of perohydroxyl (11) induce us to be very careful about the possibility of even such increase in the concentrat-

ion of atomic hydrogen. But even if we assume that at the height of about 80 km the concentration of atomic hydrogen attains $10^{7} cm^{-3}$, the concentration of ozone necessary to account for the observed intensity of the hydroxyl emission must be about $10^{11} cm^{-3}$. Apparently, this value is excessively high and is hardly acceptable. Thus, unless we are in possession of other reliable data to proceed from, all the circumstances indicated above provide evidence against an unconditional acceptance of the ozone-hydrogen reaction as the principal source of the hydroxyl emission in the upper atmosphere.

The data showing that the concentration of atomic hydrogen in the upper atmosphere is low (10) have been the reason for the attempts to find other ways to account for the appearance of the excited hydrogen in the absence of high concentrations of atomic hydrogen (12). Some of these processes have already been under our consideration (13). However, the final selection of the most effective processes is difficult due to the absence of accurate values of the constants in the supposed reactions. Therefore, we shall limit ourselves to the consideration of only one process taken as an example. This is a somewhat modernized process with the participation of the vibrationally excited oxygen molecules, which has been proposed earlier (14). The basic data bearing on this process are presented in table 3. Its most caracteristic feature is that it takes into account the atom-exchange reaction between the vibrationally excited oxygen molecules and the hydroxyl molecule. This reaction can lead to the formation of the excited hydroxyl molecules even where the atomic hydrogen is practically absent; the concentration of atomic hydrogen in the upper atmosphere may be insignificant due to an upward diffusion and dissipation. As can be seen from table 3, in comparison with the concentration of atomic hydrogen the relative concentration of the hydroxyl will increase with a decrease in the concentration of atomic oxygen. A decreasing concentration of atomic oxygen will be favourable for a long existence of the vibrationally excited oxygen molecules due to the fact that their atom-exchange reactions with the oxygen atoms accompanied by their deactivation will become less and less important. When the concentrations of the vibrationally excited oxygen molecules and oxygen atoms will be approximately equal, the concentration of hydroxyl will exceed that of atomic hydrogen about 10^2 times, for a_5 is inferior to a_4 by some two orders. For $V \sim 10^6 OH^* \ cm^{-3} \ sec^{-1}$, $a_3 \sim 10^{-10} cm^3 \ sec^{-1}$ and $[OH] \sim 10^8 \ cm^{-3}$ the concentration of the vibrationally excited molecules must be as high as $10^8 \ O_2^* \ cm^{-3}$.

In the case of the process under consideration the region of appearance of the hydroxyl emission must take in great quantities of atomic oxygen. This is possible under the following conditions: a great amount of ozone produced below the 50 km level must be transferred upwards. In the

daytime this ozone will be photodissociated by solar radiation in the region of 2000-3000 Å into molecular and atomic oxygen within a perios of not more than 1 hour. As a result, above the 90-100 km level a great quantity of atomic oxygen will be accumulated. In a vertical mixing of the atmosphere the accumulated oxygen atoms will quickly disappear at the lower altitudes either by joining to oxygen molecules or by combining between themselves in triple collisions. The process involved in the formation of the vibrationally excited oxygen molecules is illustrated in table 4. For the values of a_6 and a_7, as given in the table, the atomic oxygen will disapper in about one hour at the heights between 80 and 70 km according to the true values of these coefficients. Since the process under consideration can effectively function only with a lew concentration of atomic oxygen in the region of appearance of the hydroxyl emission, the maximum a_7 and minimum a_6 would be favourable to it. No experimental values are available for the concentration of atomic oxygen below 100 km. Its calculated values do not seem very reliable due to a very great uncertainty about the values of a_6 and a_7. New determinations of these constanto are necessary. Also rather desirable would be a direct dtermination of the concentration of atomic oxygen below the 100 km level. If in the case of the ozone -hydrogen process the most important question is the concentration of atomic hydrogen, in the process under consideration the concentration of atomic oxygen is in the centre of attention. If there are conditions favourable for the latter process, this would mean that the deactivation of the vibrationally excited oxygen molecules by hydroxyl is carried on with much efficiency, since the number of such newly formed oxygen molecules is only two or three times (see table 4) as high as the maximum number of oxygen molecules destroyed by the solar radiation in the Runge-Schumann bands and continuum.

In the case of a vertical mixing in the atmosphere the number of acts involving the dissociation of ozone into molecular and atomic oxygen as well as the number of the reverse processes leading to the formation of the non-excited ozone are considerably higher than the number of acts involving either the dissociation of molecular oxygen or the recombination of atomic oxygen. In the earth's atmosphere at a height about 30 km, to which the intensive fluxes of the photodissociating emission fail to penetrate, great quantities of ozone are accumulated. When the intensity of the hydroxyl emission is low, the amount of ozone may increase and, vice versa, when the hydroxyl emission is high, the ozone may be expended in an additional hydroxyl emission. There appears a rather interesting problem of the relationship between the amount of accumulated ozone and the intensity of hydroxyl emission for the planetary system as a whole. Apparently, the role of the vertical mixing is rather considerable in the process of the general

circulation of the atmosphere. It is difficult to imagine that this process could be homogeneous in height over any place on the earth's surface. The observed stratification of the region of appearance of the hydroxyl emission (3) is an evidence in favour of the reality of an intensive vertical mixing in the atmosphere.

With the concentration of the non-excited hydroxyl as high as 10^9 cm^{-3} and the coefficients of the rate of reaction between hydroxyl being about 10^{-12} cm^3 sec^{-1}, there will be formed nearly 10^3 cm^{-3} sec^{-1} water vapour molecules removed in this way from the reaction zone will be a considerable number of hydroxyl molecules which are quite indispensable for the appearance of the hydroxyl emission. Apart from the photodissociation of the water vapour, there is a possibility of its decomposition to form OH by the vibrationally excited oxygen molecules according to the reactions presented in table 5. Owing to this, the vibrationally excited oxygen molecules may maintain at the required level the concentrations of active hydrogen compounds in the region of appearance of the hydroxyl emission.

As the vibrationally excited oxygen molecules play a rather active part in chemical reactions, it would only be reasonable to expect that as a result of such reactions there may appear some excited products capable of deactivation by radiation. We have underlined at the beginning the relationship between the hydroxyl and other emissions. Accountable for such relationship can be their common primary source, the vibrationally excited oxygen molecules (19).

The electron-exited oxygen molecules may be part of the newly formed excited oxygen molecules. Besides, they may appear as a result of the atom-exchange reaction A (see table 6). Apart from the deactivation by radiation, the molecular oxygen state $^1\Sigma$ may also be destroyed in the B reaction (see table 6). The A reaction will play a more important part in the high region where the concentration of atomic oxygen is greater. The B reaction will be more important for the low denser regions. The molecular oxygen states $^1\Sigma$ will be better preserved at high altitudes. Since the very high values of the hydroxyl rotational temperature testify not only to a high ambient temperature but simultaneously to a higher localization of the processes involving the recombination of oxygen the growth of the electron bands of molecular oxygen in intensity with the rotational temperature of the OH bands from the 6, 7, 8 and 9th vibrational levels can be most conveniently accounted for by the growing importance of the A reaction and the diminishing importance of the B reaction at high altitudes. The higher rotational temperature of the OH bands from the 6, 7, 8 and 9th vibrational levels in comparison with the rotational temperature of the electron bands of molecular oxygen can be accounted for by the fact that the electron -

- excited molecules of oxygen during their period of existence succeed in establishing a thermodynamic equilibrium with the ambient medium, which the vibrationally excited hydroxyl molecules from the 6, 7, 8 and 9th levels fail to do.

A dinstinct correlation between the Na and OH nighttime emission can, apparently, also be accounted for by their common primary source, the vibrationally excited oxygen molecules. Table 7 presents a chain of reactions which may bring about the appearance of the Na emission at night. Given in the table are their basic laws, the possible values of the reaction rate coefficients, the concentrations of the initial products, and the Na emission intensity. All these data seem to be true to fact.

The green oxygen emission line may also be related to the vibrationally excited oxygen molecules. Table 8 presents a number of possible reactions. The A reaction is insignificant as it violates Wigner's rule. But the B reaction is rather efficient. The reaction rate coefficients in the presence of excited products may be as high as $10^{-10} cm^3 sec^{-1}$. Therefore for the concentration of the vibrationally excited oxygen molecules equal to about $10^8 cm^{-3}$ and the concentration of atomic nitrogen in the neighbourhood of $10^5 cm^{-3}$ there may appear some $10^3 cm^{-3} sec^{-1}$ oxygen atoms in the ^1S state. This is more than enough to account for the green oxygen emission line in a layer 10 km thick. The atomic nitrogen may penetrate to the region of the recombination of atomic oxygen from the superlying regions due to a vertical mixing in the atmosphere. Probably, the observed increase in the scattering of intensity values in the green emission of the night sky with the rotational temperature of the OH bands from the 6, 7, 8 and 9th levels is due to the growing circulation in the upper atmosphere. This process may sometimes involve a downward penetration of atomic nitrogen from the superlying regions, while the level of localization of the oxygen recombination process may grow in height. The C reaction may also be accountable for the appearance of the 5577 Å emission.

Since the B reaction (see table 8) produces nitrogen oxide, it may account for the relationship between the green oxygen emission line and the night-sky radiation continuum which appears when the atom of oxygen unites with the nitrogen oxide (20). Owing to the participation in this process of the vibrationally excited oxygen molecules the green emission and the night-sky radiation continuum may be related with the hydroxyl, molecular oxygen and sodium emission.

So far we have been comparing the emission appearing either in the same or in closely adjacent regions of the upper atmosphere. There is, however, a correlation between the intensity of the hydroxyl emission and those of the H$_\alpha$ hydrogen emission and the red emission of atomic oxygen, which appear at considerably higher altitudes. Apparently,

the hydrogen emission owes its origin to the excitation of atomic hydrogen which diffuses upwards from the underlying regions and is then dissipated. The amount of hydrogen in upward diffusion and the intensity of the hydroxyl emission will increase with the concentration of hydrogen or its active compounds in the region of appearance of the hydroxyl emission. At high latitudes, judging from a considerable temperature of the hydroxyl, the process involving the recombination of oxygen must usually take place at a great height. Formed at the same height is the atomic hydrogen which easily diffuses upwards due to a low density of the atmosphere. For this reason in high-latitude areas both the hydroxyl emission and the H$_\alpha$ emission are more pronounced. It is quite possible that the less distinct correlation between the intensities of the hydroxyl emission and the red oxygen emission is due to the process involving an intense upward penetration of great quantities of molecular oxygen which enters there into reaction with the ions of atomic nitrogen (see table 9). The said reaction is exothermic with the release of 6.45 ev. In this way the red emission of oxygen may appear. Simultaneously a more intensive circulation in the atmosphere may bring about a more intense hydroxyl emission. The process indicated in table 9 can be used to account for the red arcs discovered by Barbier and Roach (21,22). It may be that the place of appearance of the red arcs coincides with the place where the air from the underlying regions is sucked upwards. If this is true, in the region of the red arcs the ionosphere must be somewhat lifted, i.e. the level of equal electron concentration in it will be higher as compared to the neighbouring regions. It is also worth noticing that such latitudial bulging of the atmosphere latitudes must result in a more intensive appearance of the high-energy particles caught by the geomagnetic field. The appearance of the high-energy particles over the red arcs has already been observed (22).

Chapman was the first to point out that the emission in the upper atmosphere are due to the energy of oxygen dissociation. At that time the most powerful night-sky emission was the green oxygen line. It was assumed to be produced by the excited oxygen atoms which appear as a result of the triple collisions between three oxygen atoms, the excitation energy being derived from the energy developed by the formation of the oxygen molecule. We have long ago expressed our opposition to accepting this excitation as a source of the green emission, because the height of the region of the maximum generation of this emission, in our view, was below the region where the maximum concentration of oxygen atoms occured (19). Now we know from the laboratory experiments that the mechanism of excitation of the green emission which was set forth by Chapman, fails to account for its observed intensity (23). However, the up-to-date survey over the state of the problem of the

nature of emission in the upper atmosphere shows with an ever-greater certainty that Chapman's idea is true on a larger scale, in spite of the fact that the processes involving the excitation of the atmospheric emissions turn out to be far more complicated than the simultaneous collision of three oxygen atoms, as was previously assumed.

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Table I

$$OH^{*} + X \begin{cases} \nearrow OX + H \\ \searrow HX + O \end{cases} \quad (a_1) \qquad 1)\ 2)$$

1) $\dfrac{1}{a_o[M]} < \tau$ 3)

2) $\dfrac{1}{a_o[M]} < \dfrac{1}{a_1[X]}$

A. $OH^{*} + O_2 \rightarrow O_3 + H$ (-77.6 kcal/m)

B. $OH^{*} + O_2 \rightarrow O + HO_2$ (-54.0 kcal/m)

C. $OH^{*} + O_2 \rightarrow O_2^{*} + OH^{*}$ (0)

D. $OH^{*} + N_2 \rightarrow N_2O + H$ (-62.7 kcal/m)

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1) Here and below the asterisk on top following the symbol of an atom or molecule indicates an excited state.

2) a_1 - the reaction rate coefficient.

3) Here and below the bracketed symbol of an atom or molecule indicates their concentration.

Table 2

$O_3 + H \rightarrow OH^{*} + O_2$

$OH^{*} + \quad \rightarrow OH + h\nu$

$OH + O \rightarrow O_2 + H$

$V = [O_3] \cdot [H] \cdot a_2$ 1) 2)

After bates and Nicolet $a_2 \sim 10^{-12} cm^{-3} sec^{-1}$ (8)

Observations show that $V \sim 10^6$ $OH^{*} cm^{-3} sec^{-1}$.

----

1) V is the yield of the newly formed OH^{*} molecules cm^{-3} sec^{-1}

2) a_2 is the ozone-hydrogen reaction rate coefficient

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Table 3

$O_2^* + OH \rightarrow OH^* + O_2^*$ (a_3) 1) 2)

$O_2^* + H \rightarrow OH^* + O$ (a_4) 2)

$OH^* \rightarrow OH + h\nu$

$OH + O \rightarrow O_2 + H$ (a_5) 2)

$[O_2^*][OH] \cdot a_3 + [O_2^*][H] \cdot a_4 = V$

$[O_2^*][H] \cdot a_4 = [OH] \cdot [O] \cdot a_5$

$$\frac{[OH]}{[H]} = \frac{[O_2^*]\, a_4}{[O]\, a_5}$$

When

$$[OH] \cdot a_3 \gg [H] \cdot a_4$$

$$[OH] \sim \frac{V}{[O_2^*]\, a_3}$$

---

1) This is an atom-exchange reaction.

2) a_3, a_4 and a_5 are the corresponding reaction rate coefficient.

3) V is the yield of the newly formed $OH^*\ cm^{-3} sec^{-1}$.

Table 4

$O + O + M \rightarrow O_2^* + M$ (a_6) 1) 2)

$O + O_2 + M \rightarrow O_3^* + M$ (a_7) 2)

$O_3^* + O \rightarrow O_2^* + O_2^*$

$O_3^* + O_3 \rightarrow O_2^* + O_2^* + O_2^*$

Known from the literature (8,11, 15,16,17 and 18) are rather contradictory values of a_6 and a_7.

a_6 from 10^{-32} to 10^{-33} $cm^6\ sec^{-1}$;

a_7 from 10^{-32} to 10^{-34} $cm^6\ sec^{-1}$.

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1) M indicates any atmospheric molecule.

2) a_6 and a_7 are the corresponding reaction rate coefficients.

Table 5

Endothermic reaction

$H_2O + O_2 \rightarrow HO_2 + OH$ (-70,8 kcal/m)

Exothermic reactions

$H_2O + O_2^*$ (> 70,8 kcal/m) $\rightarrow HO_2 + O$

$HO_2 + O \rightarrow OH^* + O_2^*$ (+54,0 kcal/m)

Table 6

A. $O_2^* \; (^3\Sigma) + O \; (^3P) \rightarrow O_2 \; (^1\Sigma \; ; {}^1\Delta) + O \; (^1D)$

B. $O_2 \; (^1\Sigma) + O_2 \; (^3\Sigma) \rightarrow O_2 \; (^1\Delta) + O_2^* \; (^3\Sigma)$

Table 7

$$Na + O_2^{*} \rightarrow NaO^{*} + O \qquad 1)$$

$$NaO^{*} \rightarrow NaO + hV$$

$$NaO + O_2^{**} \rightarrow Na^{*} + O_3 \qquad 1)$$

$$Na^{*} \rightarrow Na + hV$$

$$[O_2^{*}] \cdot [Na] \cdot a_8 = V_1 \qquad 2)$$

$$\frac{[NaO]}{[Na]} = \frac{[O_2^{*}]}{[O_2^{**}]}$$

For $[O_2^{*}] \sim 10^8\ O_2^{*}\ cm^{-3}$

$[Na] \sim 10^4\ Na\ cm^{-3}$ and

$a_8 \sim 10^{-10}\ am^{-3}\ sec$

$V_1 \sim 10^2\ hV\ cm^{-3}\ sec^{-1}$

----

1) Two asterisks indicate a more excited state than the state denoted by one asterisk.

2) The number of the sodium emission quanta per cm^3 per sec.

Table 8

A. $O_2^{*}(^3\Sigma) + O(^3P) \rightarrow O_2^{*}(^3\Sigma) + O(^1D;\ ^1S)$

B. $O_2^{*}(^3\Sigma)\ [>4,25\ ev] + N(^4S) \rightarrow NO(^2\Sigma) + O(^1D;\ ^1S)$

C. $O_2^{*} + CO \rightarrow CO_2 + O(^1S)$

Table 9

$$N^+ + O_2 \rightarrow NO^{+*} + O\ (^1D;\,^1S)$$

$$O\ (^1D;\,^1S) \rightarrow O\ (^3P) + h\nu$$

$$[N^+][O_2] \cdot a_9 = \nu \qquad x)$$

For $[N^+] \sim 10^4\ N^+ cm^{-3}$, $[O_2] \sim 10^8 O_2\ cm^{-3}$ and $a_9 \sim 10^{-10}\ cm^3\ sec^{-1}$

$$\nu_2 \sim 10^2\ h\nu\ \ cm^{-3}\ sec^{-1}$$

---

x) ν_2 is the number of the oxygen emission quanta per cm^3 per sec.

4.

TEMPERATURE AND CORPUSCULAR HEATING IN AURORAL ZONE

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Summary

Results of the observations of the temperature of the polar atmosphere and some possible mechanisms of its heating are discussed.

The upper atmosphere can be heated by the ultra-violet radiation of the sun, corpuscular streams, hydromagnetic waves. A number of measurements (1-4) shows that at altitudes of 100-200 km the temperature of the night atmosphere is higher in the auroral zone than in the middle latitudes. One can believe that the latitude effect is caused by the corpuscular heating which takes place mainly in the polar atmosphere.

Let us consider temperature measurements at the atmosphere in the auroral zone.

The most ordinary are the ground observations : interferometric estimates, permitting to determine Doppler temperature from the contours of emission lines and spectro-

scopic measurements of the rotational temperature of molecular bands. One should be sure that the temperatures in such a way obtained coincide with the kinetic temperature of the medium. So either the mechanism of excitation of the observed emission should not disturb the Maxwell distribution or there should pass enough time between the excitation and de-excitation (fluorescence) so that the atom should undergo some collisions and Maxwell distribution could be restored. When observing forbidden lines λ 5577 and λ 6300 the latter condition is fullfilled up to the heights of 150-300 km accordingly. (Apparently the most probable mechanism of excitation λ 5577 and λ 6300 is an electronic impact, so Maxwell distribution remains at higher altitude as well). In the conditions of the upper atmosphere the natural width of spectral lines and collisional broadening are negligible in comparison with Doppler broadening. Turbulent motions can be apparently also neglected, so the contour of the line is determined only by thermal movements and permits to judge of the kinetic temperature of the medium.

It is most convenient to measure rotational temperatures during aurorae from bands (0,0) and (0,1) 1NG N_2^+. These are permitted bands, so if the mechanism of excitation results in deflection of populations of the rotational levels from Boltsmann distribution it will not recover till the moment of de-excitation. But as 1NGN_2^+ is apparently excited by electronic impact when the energy of the molecule is not changed one can hope that the equilibrium with the atmosphere is not disturbed. Laboratory tests showed that the proton excitation apparently also does not change the angular moment. Thus the rotational temperature determined from the bands 1NG N_2^+ should coincide with the kinetic temperature of the medium.

Spectroscopic measurements of the temperature of aurorae enable to obtain temperatures mainly of the altitudes of 80-150 km (usual forms of aurorae), more seldom ~ 200 km (red aurorae of the A type) and still more seldom for the higher altitudes sunlit aurorae). These measurements should be accompanied by the determination of the height of the radiant region. Unfortunately, this was not always done at all, so one can often judge of the height of the layer for which the temperature is determined only by the form of the light observed. A detailed survey and discussion of the obtained rotational temperatures are given by Hunten (5).

The temperature values for which heights are known fall well enough on the temperature curve of the 1961 CIRA model (6). This model is referred to the middle latitudes, so the measurements do not show any temperature rise in the direction of high latitudes. However for the given altitudes the effect cannot be great and it can be easily hidden by the erros of determination of the temperature and altitude. In general it is very difficult to

notice any temperature change at the altitudes of 100 - - 150 km depending on the intensity of the aurora, as the gradient at these altitudes is great and it is difficult to separate temperature changes with the height of the heating effects during the aurora. (The temperature changes twice at the altitude of the order of 25 km). The condition is better for the altitude of 200 km, as from this level the temperature gradient decreases and temperature changes are difficult to be attributed to the change of the altitude even if these altitudes are not accurately determined. So the determinations of the rotational temperatures of 1NG N_2^+ in the red aurorae of the type and especially in the sunlit aurorae and also interferometric observations of λ 6300 which comes from the altitude of 200 km. Rotational temperatures in the sunlit aurorae are within the limits of 800-2300°K (7-10). The fact that they are over a wide interval, allows to think that these temperatures reflect real conditions and do not depend on the mechanism of excitation. According to Størmer sunlit rays are observed at the altitudes of 400-500 km. The temperature of the normal atmosphere in these conditions, according to (6), does not exceed 1800°K.

Observations of the red line profiles (4) show that the Doppler temperature can change from 1200°K in the night almost without aurora to 3500°K for the bright red aurorae. Figs. 1-4 present the interferograms of the line

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of the laboratory source and λ 5577 and λ 6300 for different aurorae. There were no simultaneous measurements of the altitudes carried out, however the growth of intensity of the lights with the growth of temperature shows that the temperature rise is hardly connected with the growth of altitude of the luminous formation.

It should be noted that sometimes interferometrically (T.M.Mulyarchik) a non-Doppler profile of λ 6300 was observed, the intensity in the wings of the observed contour being greater than for the Doppler contour. This permits to suppose that there are some cases of superimposing of higher temperature contour of less intensity on the basic contour. However for the observations on the 17-th of December, 1958,when the temperature of 3500°K was registered the contour did not differ from Doppler distribution. At the same time with a slight difference of the temperatures of the radiant regions the resulting contour of the emission line proves to be close to Doppler contour.

As it is difficult to conceive such a night temperature at these altitudes within the bounds of the exciting models of the atmosphere one should admit the fact of intense heating of the atmosphere during aurorae.

Besides such a temperature rise of the polar atmosphere during some separate days for aurorae forms, a systematic rise of Doppler and rotational temperatures in the auroral zone is observed. The effect is not great but

it can be traced by interferometric measurements of green and red lines (3,4) and determinations of the rotational temperature of OH (1,2) in the nightglow. (It is true that nothing is known of the variations of the height of the glow of these emissions).

The most attractive variant of polar atmosphere heating is warming up by corpuscles. Optical observations of the nightglow of the polar sky and aurorae as well as rocket measurements of corpuscular streams permit to make estimates of the quantity of energy (entering) in the polar atmosphere.

There exist other possible mechanisms of polar atmosphere heating. In the first place we mean magnetic-hydrodynamic waves (11). If the mean amplitude of these waves over the ionosphere reaches some hundreds of gammas at frequencies of 0.1 - 10 herts, the dissipation of the energy of similar waves at the height of 200-300 km can prove to be essential for the heat balance of the atmosphere. It may be that such conditions take place during magnetic storms (12). Magneto - hydrodynamic waves with lower frequencies (periods 4-8 min) and amplitude of the order of $10^2 \gamma$ are discovered during ground observations (13). One can suppose that there exist such waves of higher frequency. It is necessary to study quick variations of the magnetic field at high altitudes and on ground to provide the material for confirmation of this supposition.

Other sources of heating (meteors,acoustic waves from the troposphere etc.) are not significant in the heat balance of the polar atmosphere (14).

It is difficult to determine the amount of the energy of the corpuscular stream changing to heat during its interaction with the atmosphere. Various estimates (15,16) differ from each other, but, apparently, the greater part of the energy reradiates in the form of electromagnetic energy (emission in the visible, infrared and especially far ultraviolet region of the spectrum).

We assume the amount of the electron energy changing to heat to be equal to 20%. Direct measurements of electron fluxes during a weak (apparently, IBCI) and strong (IBCIII) aurora gave values of the order of 1-2 and several hundred $erg.cm^{-2}sec^{-1}.stered^{-1}$ (17). No rocket measurements in polar areas take place without aurorae. Electron fluxes in this case can be estimated according to optic observations of the bands λ 3914 and λ 4278 1NGN$_2^+$ (15). For soft electrons the energy lost to form one ion-pair is equal to 35 electronvolts (18). At the same time 2% of the formed ions radiate in the band of (0,1) 1NGN$_2^+$ (19,20). Apparently, electron current S equals to

$$S_{erg} = 2,8 \cdot I_{3914} \text{ (kR)}$$

$$S_{erg} = 6,6 \cdot I_{4278} \text{ (kR)}$$

Measurements in Loparskaya in the period of IGY permitted to estimate in electron flux when there were no aurorae in 1 $erg.cm^{-2}sec^{-1}$ (15). In the minimum of solar activity this value is less, but the intensity of the band λ 4278 Å is never lowered below 50 R, which gives estimate of the corpuscular stream at 0.3 $erg.cm^{-2}sec^{-1}$.

It is known that the microwave radiation of atomic oxygen is a marked cooling factor of the upper atmosphere. According to estimates of Bates (21) and Nicolet(22) the intensity of radiation of $\lambda = 63\mu$ over 150 km is about 0,1 $erg.sq.cm^{-1}sec^{-1}$ and over 100 km about 1 $erg.cm^{-2}sec^{-1}$. Thus if the corpuscular stream reaches the height of 100 km its intensity is 1 $erg.cm^{-2}sec^{-1}$ which corresponds in our suppositions to thermal efficiency of 0.2 $erg.cm^{-2}sec^{-1}$. Warming up of the atmosphere over 100 km begins from the intensity of the corpuscular stream 5 erg ($I_{3914} \sim 2kR$). Let us note the fact that the bright aurorae (IBCIII) can consequently provide though short but intense heating of the atmosphere. Direct measurements of the intensity of electron fluxes gives values of the order of 10^3 $erg.cm^{-2}$, which corresponds to the thermal energy of 200 $erg.cm^{-2}sec^{-1}$, released up to the height of 100 km (2.10^{-5} electron volts/particle sec).

Consequently, noticeable heating of the atmosphere by the corpuscular stream can be provided during an order of an hour.

Note

In 1961 and 1962 the authors evaluated temperature from twilight flash of helium λ 10830 Å. A Fabry-Perot étalon with an image converter was used. One of the photographs is shown in Fig.5. The width of the helium line component is no larger than 0.15 Angström (23,24). This method was used in spring 1962 to study the H_{α} line in the nightglow. The width of the geocorona H_{α} line proved to be less than 0.3 Å. Observations carried out for antisolar point enabled to detect some decrease of intensity of the H_{α} line in this point which dropped off about to halve (taking into account tropospheric scattering).

Legenda

Fig.1. Interferometric photograph of the line λ 5577 in aurora (h ~ 200 mm).

Fig.2. Photograph of the line λ 6300 Å in an A type aurora of moderate intensity.

Fig.3. Photograph of the line λ 6300 Å in a bright A type aurora

Fig.4. Photograph of the laboratory source (yellow line of krypton).

Fig.5. Interferogram of the line He λ 10830 Å in twilight.

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5.

HELIUM IN THE UPPER ATMOSPHERE

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Summary

The paper deals with the excitation of helium emission in the upper atmosphere. Emission of λ10830 Å is observed only in sunlit atmosphere and appears due to fluorescence. The excitation of helium emission, λ 10830 Å, essentlially depends on ultra-violet solar radiation with $\lambda < 304$ Å and λ584 Å. The paper examines varieties of this radiation.

During the IGY and in the period that followed the Institute of Physics of the Atmosphere of the U.S.S.R. Academy of Sciences has been engaged in research into the problem of the upper atmosphere emission. Displays of twilight enhancement of λ 10830 Å helium and λ 8446 Å oxygen emission were undoubtedly among the most interesting phenomena we had occasion to detect. The oxygen line of λ 8446 Å was observed at Zvenigorod during long summer twilights with an exposure of about two hours in unperturbed magnetic conditions (1).

The existence of this emission which appears in twilight as a result of absorption of the L_β solar line by atomic oxygen was predicted by Shklovsky (2). The mean

measured intensity of λ8446 Å emission was estimated at 13 Rayleighs. This intensity is lower by one order of magnitude than the intensity estimated by Shklovsky and by one order higher than the intensity calculated by Brandt (3).

For all that, the detection of helium emission, λ10830 Å, remains the most interesting feature. Helium was long ago known to exist in the atmosphere, but its content in the upper atmosphere, beginning from the first computations made by Jeans (4) and until recently (5-8) could be determined only by purely theoretical calculations and on the basis of different assumptions of its origin in the terrestrial atmosphere. Many attempts have been made to discover helium lines in the visible region of the spectrum, of aurorae and all of them have failed. It was not until image converters came into use that it became possible to observe helium emission, λ10830 Å, for the first time in an aurora on February 10-11, 1958 (Mironovet al.) (12,13). Later, Fedorova (14,15) who made systematic observations of aurorae discovered new evidence in support of this phenomenon.

A twilight enhancement of helium emission λ10830 Å in the absence of aurora was observed by the author with the help of a spectrograph (16-19) and by Shcheglov who used a Fabry-Perot étalon (17-21). We have also succeeded in recording helium emission during the solar eclipse on February 15,1961, when observations were conducted from an aircraft (Shuiskaja) (22).

Unfortunately, information on the observations of $\lambda 5875$ Å helium emission (23,24) apparently leaves out of account the blending effect exerted on $\lambda 5875$ Å emission by the hydroxyl band branch (8,2). According to Fedorova (25), the intensity of helium emission $\lambda 10830$ Å in sunlit aurora shows a certain connection with the solar activity.

We know that helium emission of $\lambda 10830$ Å is observed only when the sun illumines the upper layers of the atmosphere both during aurorae and in ordinary twilight with absens of aurorae. In this case the intensity of the "resonance" line, $\lambda 10830$ Å, is rather high while the intensities of the subordinate lines are so negligible that nobody can so far claim to have discovered them authentically. All this undoubtly indicates to the fact that helium emission of $\lambda 10830$ Å can be caused only by a resonance fluorescence of helium atoms in the 2^3S metastable state in solar radiation (26-28).

The process of excitation of $\lambda 10830$ Å emission by helium atoms with an energy of about 256 kev was examined by Malville (23). The value of the relationship of the $\lambda 10830$ Å and $\lambda 5875$ Å line intensities he has calculated (0.09) disagrees with the observation data because $\lambda 5875$ Å emission has never been registered for certain. According to the computed value (0.09), its intensity may reach several thousand Rayleighs in aurorae. However, even if the emission

of $\lambda 5875$ Å was present in the aurora on February 10-11, 1958, its intensity could not be over 10 Rayleighs as it follows from the published spectra (12), whereas the intensity of $\lambda 10830$ Å is very high. Besides, the helium emission of $\lambda 10830$ Å should have been present also in the atmosphere which was not illuminated by the sun which was not the case. For this reason, the role of the process of helium excitation examined by Malville must be very insignificant.

The lifetime of the 2^3P excited state initiating the radiation of the $\lambda 10830$ Å line may be determined only by the probability of a spontaneous transition to the 2^3S state. Therefore, the number of transitions $2^3S - 2^3P$ due to radiation absorption should equal the number of transitions $2^3P - 2^3S$ with the radiation of the $\lambda 10830$ Å line (Table 1). The intensity of the emission $\lambda 10830$ Å in twilight amounts to about 1,000 Rayleighs while in aurora it can reach several tens of kilorayleighs. This is in good agreement with the population in the 2^3S helium metastable level having from one to several tens of metastable atoms per cubic centimetre.

Examination of the entire combination of the processes causing the excitation of the metastable state of helium, 2^3S, has shown that the priority belongs to the following two processes: excitation by electrons with an energy of about 25 ev and excitation due to solar radiation in $\lambda 584$ Å

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and λ 537 Å lines of helium. Electrons with an energy of about 25 ev may appear in the upper atmosphere as a result of the ionisation of atmospheric atoms and molecules by electrons with an energy of about 10 kev and the ultra - -violet solar radiation with $\lambda < 304$ Å (29,30). Electrons with an energy of about 10 kev have been already discovered by means of rockets and artificial satellites (31-36). The intensity of the ultra-violet solar radiation has been likewise repeatedly determined with the help of rockets (37-38).

A system of steady-state equations has been devised for computing the intensities of various helium lines. The calculations involved only the first five excitation levels of orthohelium and parahelium. The effective excitation cross-section of the 2^3S metastable level by electrons with with an energy of about 25 ev was taken from Schultz's data (39) and for the other levels from Allen (40) and Yakhontova (41). Exchange transitions of helium atoms from the 2^1S state to the 2^3S state possess a large effective cross-section during collisions with ordinary "thermal" electrons. Kondratiev (42) and Smith and Muschlitz (43) estimate this effective cross-section at $\sim 3.10^{-14}cm^2$. This inadvertently promotes the role of the resonance excitation, by solar radiation in the λ584 Å and λ 537 Å lines, of the parahelium levels, 2^1P and 3^1P, from which the helium atoms can be transferred with radiation to the 2^1S level. Exchange transitions between higher singlet and triplet states of helium during collisions with electrons and helium atoms

in the ground state also have large effective cross - -sections. These processes have been studied by Lin and Fowler (44) and John and Fowler (45). However, the n^1P levels are less populated in condition of the terrestrial atmosphere. For this reason, the role of exchange transitions from all parahelium levels, except for 2^1S, will be negligible. Incidentally, this is confirmed by the absence of λ 5875 Å emission.

The solution of the system of steady-state equations has yielded for helium the dependence of the population of the 2^3P level and, hence also the intensity of the λ 10830 Å emission, upon the content of electrons with an energy of about 25 ev in the upper atmosphere and the intensity of the ultra-violet solar radiation (18, 19, 46) (Table 2).

The functions φ, ξ and ψ describe, respectively, the role of the processes of excitation by electrons with an energy of about 25 ev and the processes of recombination and ultra-violet solar radiation in λ584 Å and λ537 Å. Since the degree of helium ionisation up to 2,000 km is of the order of 10^{-3} (47-49) and the electron density is close to 10^4 cm^{-3} the effect of the recombination processes can be frequently neglected. The function ψ which determines the role of the ultra-violet solar radiation is directly proportional to the intensity of the λ 584 Å and λ 537 Å lines when the concentration of ordinary "thermal" electrons exceeds 10^2cm^{-3}. The functions φ and ψ also depend on the electron concentration and the temperature in the upper atmosphere which are the factors determining the effect of the processes of electron exchange when parahelium passes into orthohelium.

However, the transparency of the terrestrial atmosphere differs in the wavelengths $\lambda 584$ Å and $\lambda < 304$ Å. Absorption in the wavelengths $\lambda < 304$ Å, and also in $\lambda 584$ Å far from the centre of the line, will be brought about by the photoionisation of oxygen atoms and nitrogen molecules. The heights of layers, which correspond to an optical thickness equal to unity, in the wavelengths $\lambda 584$ Å and $\lambda < 304$ Å will be 350 km and 300 km, respectively, at an oblique incidence of rays. The heights corresponding to a ten-fold attenuation are estimated at 300 and 250 km. The effective values of photoionisation cross-sections were taken from Dalgarno and Parkinson (50). In the centre of the $\lambda 584$ Å line the absorption will be also effected by helium atoms. Inasmuch as the absorption coefficient at $T \sim 1500^{\circ}K$ is about $10^{-13} cm^2$ (51,52) the atmospheric layer will be optically thick when the sun rays fall oblique. It is extremely difficult to solve the problem of the diffusion of resonance radiation in an optically thick medium for a spherical atmosphere in the case of almost pure scattering--this problem still awaits its solution. For a plane - parallel medium the problem was investigated for some limiting cases by Ambartsumyan (53), Sobolev (54) and Chandrasekhar (55). Brandt examined only the diffuse reflection of radiation $\lambda 584$ Å (56). It stands to reason, however, that the

role of $\lambda 584$ Å and $\lambda 537$ Å emissions in the excitation of the 2^3S helium metastable state will be quite impressive at the heights of 1,000 km and more. At lower heights the helium atoms will be excited by electrons with an energy of about 25 ev which appear during photoionisation by solar radiation with $\lambda < 304$ Å (46). It should be noted in this connection that the role of $\lambda 584$ Å radiation evaluated earlier (18,19) was apparently somewhat exaggerated. However, to arrive at the final solution the problem of the diffusion of $\lambda 584$ Å radiation should be studied in greater detail.

We have pointed out elsewhere that the presence of helium in the terrestrial atmosphere was known long ago. The study of the earth's satellites acceleration (57) made it possible to specify more accurately the data of atmospheric density (58), which were obtained on the basis of the helium dissipation theory. Observations of helium emission, $\lambda 10830$ Å, yield almost identical results. However, the following is far more important. As has been shown, ultra-violet solar radiation is an essential factor in the processes of excitation of $\lambda 10830$ Å helium emission. For this reason, the investigation of the emission, $\lambda 10830$ Å, allows ordinary ground observations of solar radiation with $\lambda 584$ Å and $\lambda < 304$ Å to be undertaken.

The problem of variations in the ultra-violet solar radiation is not yet completely solved both from an experimental and theoretical points of view. Analysis of the data provided by rocket research, including L_{α} spectroheliograms, leads us to the following conclusions (59).

1. The temperature of the effective radiation layer is of the order of 20000°K.

2. The temperature in the active and unperturbed regions of the sun is almost the same.

3. The density in the active regions is approximately by less then an order of magnitude higher than in the quiet regions.

4. The total solar radiation flux in the L_α line can change negligibly (by two or three times) during the entire cycle of solar activity.

These assumptions concerning the nature of the active regions agree generally with the model of the chromosphere devised by Ivanov-Kholodny and Nikolsky (60). It follows therefore that if the radiation of the HeI λ584 Å and apparently HeII λ304 Å which forms, like L_α, in an optically thick layer, arises in the same cases as L_α, then the variations of the intensity of these lines should be of the same order of magnitude as for L_α. The same is true of L_β. For this reason the active formations on spectroheliograms in the helium lines may be expected to vary 5-10 times. Hence, the variation of the total radiation flux should be on an average 2 to 3 times even if the area of active formations proves greater than that observed on L_α spectroheliograms.

Matters appear quite different an regards the study of the sun in the region with $\lambda < 300$ Å. The lines in this spectrum region arise in an optically thin layer (52).

Since the intensity of the lines in this case is proportional to the square of the electron density the local brightness of the disturbed areas on the sun in these lines may be higher by two orders of magnitude than in quiet areas. Therefore, the total radiation flux with $\lambda < 300$ Å can vary less than an order On the basis of these data it can apparently be expected that solar radiation will be correlated with the area of the faculae (59).

In this way, taking into account the anticipated variations of the ultra-violet solar radiation, it can be assumed that in aurora electrons with an energy of about 10 kev and a solar radiation with $\lambda < 304$ Å can make a commensurable contribution to the formation of electrons with an energy of about 25 ev. During ordinary twilight and by day under quiet conditions the ultra-violet solar radiation with $\lambda < 304$ Å will apparently make a decisive contribution to the intensity of the λ 10830 Å emission.

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Table I

$$n_{2^3S} \cdot w\, \rho\, B = A \cdot n_{2^3P}$$

$$I = A \cdot n_{2^3P} \cdot H_{He}$$

$$n_{2^3S} = \frac{I}{w\, \rho\, B \cdot H_{He}}$$

w — dilution factor,

A, B — Einstein transition values,

ρ — density of λ 10830 Å solar radiation,

H_{He} — height of homogeneous atmosphere for helium,

I — λ 10830 Å line intensity in quanta

Table 2

$$\frac{n_{2^3P}}{n_o} = F\left(1 - \frac{n^+}{n_o}\right)\varphi + \frac{n^+}{n_o}\xi + \left(1 - \frac{n^+}{n_o}\right)\psi$$

n_o --- full concentration of helium,

n^+ --- concentration of He^+ ions,

F --- flux of electrons with an energy of about 25 ev.

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